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INSTRUMENTATION FOR BIOLOGICAL RESEARCH

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INSTRUMENTATION FOR BIOLOGICAL RESEARCH

1.0 ACKNOWLEDGEMENTS

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Mr. L. Mitchell, Jr., of the Allegheny-Ludlum Steel Corporation, and Mr. G. Bohachevsky of Magnetic Metals Company were most cooperative and helpful in their efforts to make known to us the many practical problems to be considered in the handling of magnetic materials.

2.0 INTRODUCTION

The developments and areas of study in basic research which are described in these volumes were undertaken for the direct and long-term benefit of the experimental biologist. This statement is made to indicate specifically the intent which has been adhered to by each contributor to the effort described.

Our efforts have been channelled as follows:

The Managed Energy Terrella
The Multi-Channel Implantable Telemeter
Final Debugging and Adjustment of the Mark I Data Handler at Princeton

The MET, or Managed Energy Terrella, grew from a concept put forth in 1954 by R. M. Goodman, one of the authors of this report. The concept, in its simplest form, states that in the (any) biological experiment one wishes to control and/or measure all parameters which can interact in any way with the biological material under study. The justification for this concept is clear enough and will not be argued here. As a matter of fact, biologists, long noted for their discernment and care in dealing with the experimental difficulties presented them by living systems, have attempted to follow the MET concept as well as they were able with the tools at hand. However, the MET concept, while simple in general statement and philosophy, presents a related series of extremely complex considerations—each of which must be studied for itself and for its useful contribution to a workable MET.

The initial attack on the total MET concept is described in this report. These first steps are fundamental and will, we believe, in themselves prove directly useful to the experimental biologist. It is our serious hope that the work will go on so that continuous additions to a workable MET concept can be made consistent with the state-of-the-art in the physical and biological sciences. It is certainly true that there is probably no end to the "general" MET development. It is equally true that in parallel with the path of basic research in the MET is a path replete with direct and immediate applications to an improved experimental biology. And it is not unwarranted to state that all areas of experimental biology are subject to the benefits from the MET study. In substance, this means that continued study of the MET approach will result in experimental regimes and devices of direct application to the testing of biological hypotheses of evergrowing complexity and sophistication.

With due respect and considerable humility, we ask that the experimental biologist join hand and mind with us in the consideration of the MET. We believe that the sort of "total awareness" in experiment consideration we are attempting to evolve is not only good biology, but is "good science."

The bases for these comments and viewpoints will be found in the body of this report.

The multi-channel implantable telemeter development described herein is based on a serious need on the part of the life scientist for comparative as well as differential, simultaneous, measurement of physiological parameters. Equally important has been the consideration of implant lifetime, its physiological characteristics and its cost. The development is not yet complete, but substantial progress has been made.

Our work with the Mark I Data Handler installed at Princeton University Moffett Laboratory in 1964 has continued and with considerable success. Details and data will be found herein.

3.0 THE MANAGED ENERGY TERRELLA

3.1 INTRODUCTION

While this study has been called a "Stimulus-Free-Volume" feasibility study, it should not be inferred that stimulus control or stimulus measurement is to be ignored in this study. This study will be concerned with a region or space suitable for biological experimentation in which energy of whatever form and with whatever time dependence will, if possible, be controlled or managed, and if not manageable, then known by measurement.

It is energy in some form, with or without some time dependence, which stimulates biological entities to change or react. Energy is essentially the common factor be it temperature, magnetic fields, light, gravitation or other stimulus. In many cases this energy may be almost vanishingly small (with respect to our measuring instruments) and still be capable of producing a reaction. This simply attests to the high sensitivity of biological detectors or sensing mechanisms (3-1).

This study could then be named more advantageously a Managed Energy Region Feasibility Study. Another terminology which seems to be most appropriate is Managed Energy Terrella or MET.

These energies are then some form of biological stimuli. Not just those energy forms with magnitudes known to produce a biological stimulus will be considered in this study, but any form of energy to which the biological organism is subject.

In beginning a study of this sort we must first delineate an overall picture which will then gradually and step-by-step be broken into its components. Each component part of the study will then be examined with as much care as time allows.

One way in which the general problem can be categorized is to consider the various modes in which the energy may manifest itself. This break-down may be as follows:

1. Electromagnetic Energy Fields

   This, in general, will include:

   Electrostatic fields

   Magnetic fields

   Radiation fields all wavelengths, light, radio, X-rays, cosmic rays, etc.

2. Gravitational, or Acceleration, or Force Fields

   This will include gravity, vibration, gas winds, noise, acoustics, etc.

3. Chemical Sources

   This includes gas composition, food composition, etc.

   Enclosure materials - outgassing, ingestion of

These three categories should cover all the possible energy sources which may, or may not, have a stimulus effect on a biological specimen.

A second step in the analysis of a MET system is to consider all the energy sources included in the above listing as inputs to a "black Box," the black box being the biological entity being studied. Also, we will consider any outputs of the black box as being the responses of the biological entity, (whether or not this is correlated to any specific input). An attempt at correlation is then made between the inputs and the outputs of the black box. For any correlation to be valid and useful, a hypothesis concerning the functional relationship of the input to the output is necessary.

On the other hand, all correlations of input to output should be examined for expected as well as for unexpected relationships. Any unexpected high correlations, if a reasonable hypothesis can be made relating the input with the output, then constitute a discovery of a new biological phenomenon. This is one reason why as many variables as possible, or all those that are known to exist, should be controlled or monitored.

The next step in the analysis of the MET system is the identification of the input and output variables of the black box. Beyond the identification we must determine the magnitude or ranges of these input and output variables and a listing and correspondence of possible biological entities to which these inputs and outputs are related.

This identification, listing and relationships will be obtained from the literature. This information should not be taken at face value from the literature but, insofar as possible, analyzed and evaluated as to its worth and reliability. In addition, the sources of all information as to magnitude and kind of inputs and outputs should be cited so that any investigator in the future may apply his own criteria to the information based on his own knowledge of the source. Such a compilation is found in the Appendix as Environmental Parameters and Biological Interactions.

The next level of analysis should then consist of a technical evaluation or analysis of the various techniques which have been used, or which may be used to detect, measure and control the inputs and to detect and measure the outputs. The interrelationships between inputs, outputs and inputs and outputs should also be investigated insofar as possible. The interference with or disturbance of the bio-entity by any of the measuring techniques must be determined and if possible eliminated. The interference with the measuring techniques by the bioentity must be clearly determined and eliminated. And lastly, the interference with or disturbance of the measuring techniques by any of the inputs or outputs must be determined and eliminated.

At this point it can be seen that this analysis is not a simple task. It is also clear that simple or not—it is a fundamental requirement. If we consider only 10 input variables, 10 output variables and 10 biological entities, which may be subjects of the same species, there will then be possible 10 x 10 x 10 = 1000 separate interrelationships which must be analyzed. This number can be increased by possible delayed effects, or effects due to a combination of variables which do not yield a simple sum of the outputs but are interrelated. In general, it is necessary not only to determine whether these relationships exist but to determine their magnitude and time relationships and whether or not they are of sufficient magnitude to interfere with a measurement or control. In a case where there may be as many as 1000 interactions this is indeed a formidable and time consuming task, but it must be done. Because of the very nature of the studies to which an MET may be applied, even those interactions (perhaps we should say especially those interactions) which in the past have been assumed to have no interrelationship must be carefully re-examined.

For interactions where nothing is known, we have a field where inquiry may yield interesting results. At least, the MET should make it more possible to investigate those interactions adequately. Sollberger (3-2) in his book, Biological Rhythm Research, has some pertinent comments on rhythms which express the same philosophy as we are attempting to develop for the MET.

He says: "Actually in our experiment with constant external conditions, we can never be quite sure: 1) that we know all the physical forces acting upon the body or all the frequencies which may appear in them, and 2) whether they do not still act upon the organism interfering in some way with the endogenuous rhythms. The ideal site for our experiments would, presumably, be the emptiest place in space between the galaxies, though ... who knows? We do not know the forces which create new galaxies out of hydrogen clouds. Vast magnetic fields seem to be involved in the creation and sustenance of matter. Where in space do radiation, magnetism and gravitation really cease to operate? What is gravitation?"

And later he comments: "As a matter of fact, a short contemplation shows that the scope of these problems (interrelation of synchronizers and rhythms) is almost frightening to the modern mind. These are the holistic concepts of all things being interrelated. Gravitation and magnetism are dependent on the position of distant celestial objects. Why that's almost astrology ... Clearly we must be careful in accepting such statements, but also in rejecting them because of the negative associations they carry in our minds. The problem constitutes perhaps one of the most fascinating challenges to the biological scientist of today."

3.2 INFORMATION FLOW DIAGRAM

Let us consider a living organism from a primitive point of view. The organism need not be primitive, but the reference point from which it is considered must be basic, or primitive. We have elected to do this from an energy standpoint. Energy can be of various grades, a high grade such as light or a chemical bond, or a low grade such as heat. A change in energy from a high grade to a low grade can be described as an increase in entropy, from a low to a high grade as a decrease in entropy, or an increase in negative entropy or negentropy. Entropy can also be considered as a measure of orderliness. An increase of orderliness is an increase in negentropy. Schrodinger (3-3) has pointed out that the characteristic of life is the production of order from order. Maintenance as well as reproduction of biological order (an increase of orderliness) both depend on the same process, metabolism, (a decrease in orderliness), which is correlative to an increase in entropy. While, on the whole, entropy increases, in particular, order is increased so negentropy increases. Brillouin has proposed a generalized negentropy principle which takes into account the value of the organization or information. The increase of negentropy or order, which is equivalent to information which is useful or valuable information to the living system, is the information in which we have an interest. For example, the difference in negentropy of the system of letters "a e m t" when ordered as "meat" and ordered as "team" is the same if considered as producing a recognizable English word. The information value of these two words, however, is quite different if considered by a football coach.

Every living organism is a highly ordered mechanism. This ordering is maintained and reproduced at the expense of energy. This energy is derived from outside the organism. A large part of this energy is in the form of chemical bonds which is transformed to the required kind of energy for orderliness of the organism. Some energy is of a high order and contains information which the organism can use directly to maintain its orderliness. Some energy is of a form, and contains information, which tends to reduce the orderliness of the organism and against which the organism reacts at the expense of other energy. In effect, a living organism is a receptor for energies of various kinds containing information of various value to the organism. These energies and their associated information values are transformed, that is, changed to positive value, or an increase in negentropy, to the benefit of the organism. This transformed energy and this increase or change in information value can be detected by appropriate means and can be considered an output of the orderliness "drive" of the organism. Maintenance of the organism, that is, maintenance of biological order is one aspect of life, reproduction being the other (3-3). Both of these have their characteristics which are essentially responses (that is, output) of the organism to the energy and information input to the organism.

It is these energy and information inputs to and outputs from the living organism which the life scientist studies in whole or in part (3-4). Many of the inputs may interact with each other, or interact in the organism to produce outputs different from any of the inputs alone. Some inputs may interact with the organization of the living organism with various time scales or delays. These time interactions may be simple delays, they may be oscillatory, or they may interact with an oscillatory organization (e.g. rhythms) in the organism (3-2, 3-4, 3-5, 3-6). In any case, it is necessary to know as far as possible exactly what the various inputs to the organism are in order to better interpret the many and varied responses, or outputs, of the organism.

In order to help visualize this input-output functioning and the relationship of the observer in the input-output functioning, it became imperative that some kind of organization be applied to this problem and an orderliness brought out of the many diverse and nebulous ideas.

In an attempt to summarize concisely and graphically, and yet generally, a diagram indicating the flow of energy and information was evolved. Many phases, kinds and types of diagrams were drawn and studied in an attempt to obtain a simple, but comprehensive schema. Essentially the problem was one of depicting the functional and logical relationships between all possible parts and functions in a biological experiment, neglecting none and yet being sufficiently general to obtain simplicity. By utilizing ideographic representation rather than a verbal description clarity and organization can be brought to the ideas and concepts of energy and information as applied to the biological experiment. A very simple view of any biological experiment involves at least an Experimenter and a Living Organism. This Living Organism is investigated by the Experimenter by observation usually involving some kind of instrumentation. Such instrumentation is located between the experimeter and both the inputs, or stimuli, which are applied to the Living Organism, and the outputs, or response of the organism.

As a first and most primitive logical diagram showing the relation of the Experimenter to the Living Organism via the flow of information and energy we have Figure 3.2-1.

This shows the 1) Living Organism, 2) output instrumentation connecting this organism to 3) the biologist and 4) the input mechanism connecting the biologist to the organism. This diagram shows that information and energy comes from the organism, that primarily this information is conveyed to the Experimenter, that different information is conveyed from the Experimenter to the input apparatus and thence to the organism, this information being carried by some form of energy. Thus the experimental cycle is completed and the experiment proceeds. Note that there is also energy and information entering and leaving the living organism about which the Experimenter has neither knowledge or control. One of the greatest problems of the Experimenter is (in general) to minimize these unknown inputs and outputs. Even the knowledge that these inputs and outputs are truly not pertinent to his experiment even if their magnitude and phase are unknown is sufficient knowledge of them to make them no longer unknown. Often inputs are assumed not pertinent without true knowledge that they are not pertinent. This can be a dangerous assumption.

A more useful concept of the experiment cycle will show a breakdown of the functions which are incorporated in the four boxes or nodes of

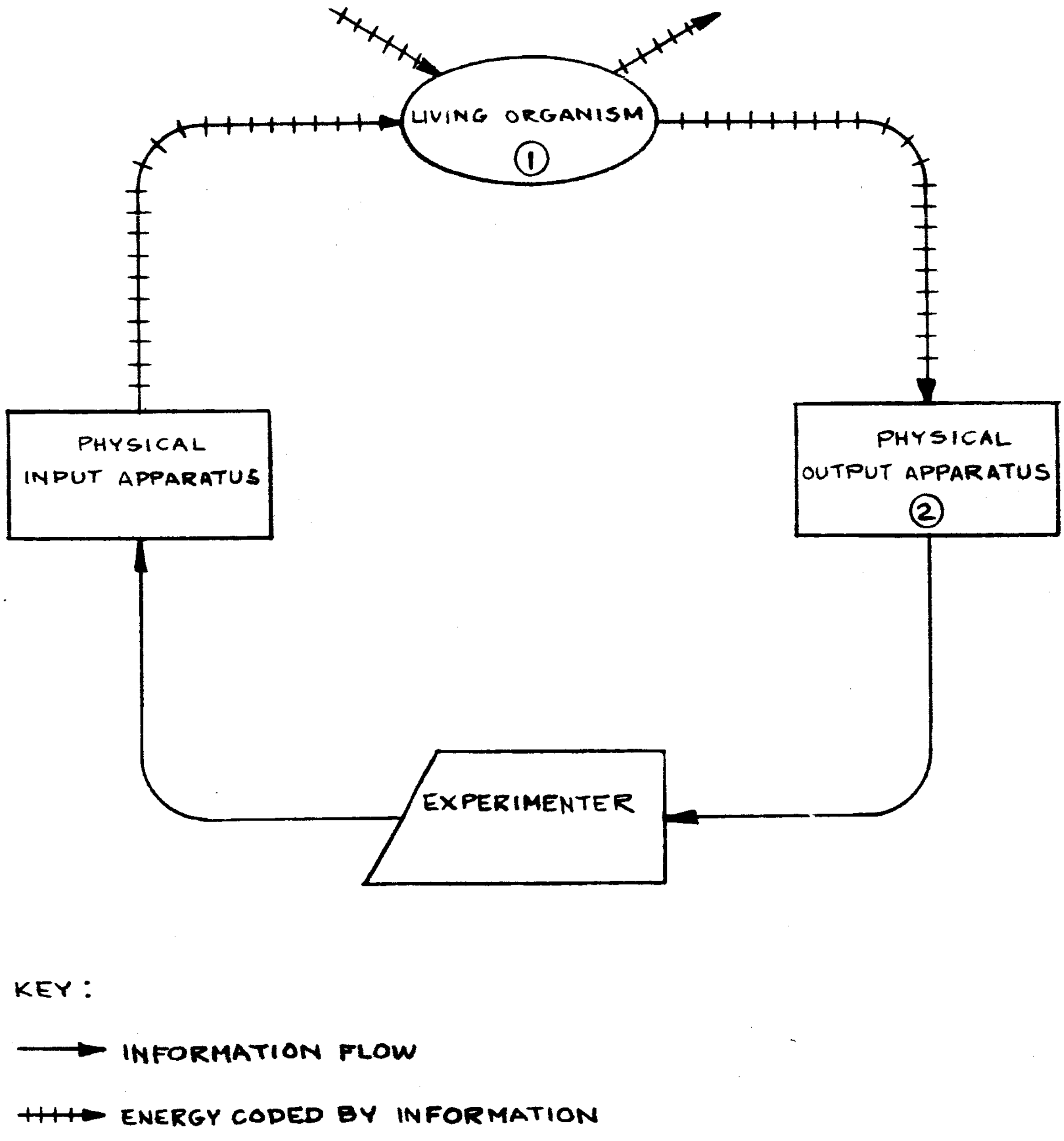


Figure 3.2-1 Primitive Information Flow Diagram

information and energy shown in Figure 3.2-1. This breakdown is shown in Figure 3.2-2. The (1) Living Organism is now called a bioentity. (A list of definitions follows.)

The output node remains undivided and is called the (2) output detector. The experimenter node is subdivided into the functions of the experimenter and his extensions into various mechanical or electrical or computer aids. These subdivisions are (3) correlation and Data Processing, (4) Results, (5) Hypothesis, (6) Experiment Design. The Input Apparatus is divided into an (7) Input Control and (8) an Input Detector. Further division is of course possible and when a close examination of any node is made, subdivision of it will be added as necessary. For our present purpose, however, the eight categories of functions, operations, entities or, in general, nodes will be sufficient.

DEFINITIONS:

Input Stimulus, environmental conditions, etc.	Any kind of energy which may or may not produce an output in a biological entity. It may be unknown or known. This energy may or may not carry information of use or value to the bioentity.
Output (response, reaction)	Response of any kind by a biological entity to any input. This energy may or may not carry information of value to the experiment. An output may be known or unknown.
(1) Biological Entity (bioentity)	The Biological Entity is the living organism or group of organisms that may be considered as a whole in the particular experiment under investigation.

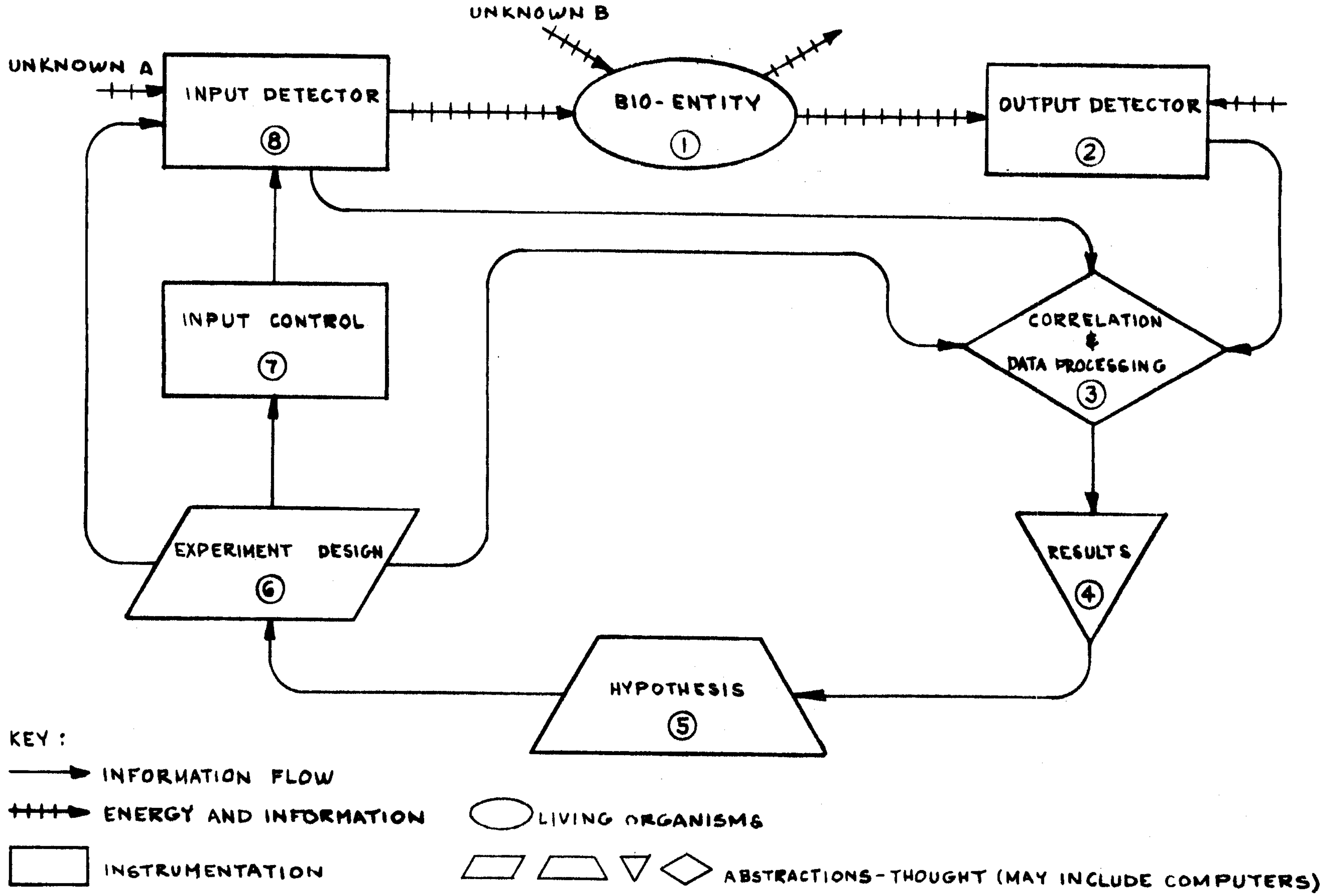


Figure 3.2-2 Information Flow Diagram - Stage I

(2) Output Detector

Any device or group of devices that detects, measures and indicates the characteristics of any single output.

(3) Correlation and Data Processing

This includes both the mental and the physical processes of bringing together the logical constraints of the hypothesis and experiment design, and the data from both the inputs and output detectors. This information and data are then processed by mathematical theory (including statistical theory) with the aid of electronic or other computing devices where necessary. This processing may be in real time (i.e on-line) or at a time subsequent to the particular experiment run.

(4) Results

The final, reduced and meaningful numbers containing the information of significance resulting from the correlation and data processing. When they are compared to the numbers predicted by the hypothesis, they are used with their limits of validity to form new or improved hypotheses.

(5) Hypothesis

The hypothesis is one or more questions asked by the experimenter about the relationships between various entities of the experiment. It represents basically what he wants to find out, but not how he intends to find what he wants. The questions fall into two categories of different value.

The first can be represented by the question (I) Is A (cause) related to B (effect) through the subject (5) of the experiment. The second question can be represented as—Given (I) then (II) is the relationship A to B through 5 described by the function C? Each question can be answered by a simple "Yes" or "No." If, as in all practical cases, sufficient information is not obtained, for one reason or another, by the experiment to absolutely state "Yes" or "No" then some degree of confidence or doubt is assigned to the answer. This doubt may be sufficiently large so that the answer is effectively "Maybe."

(6) Experiment Design — The experiment design consists of both the practical and the theoretical plan of the experiment. It includes the use of the Theory of Experiment Design. It projects to the reliability of the Results (4) and the confidence to be placed in the answer to the Hypothesis (5). It chooses the number and kinds of apparatus to be used in the Input Detectors and Controllers and in the Output Detectors. It is where the limitations of the physical apparatus are mated with the power of theoretical techniques.

(7) Input Controller — Any device or group of devices which changes, controls, modulates, eliminates or otherwise acts upon any single input in a predetermined way.

(8) Input Detector — Any device or group of devices that detects, measures and indicates the characteristics of any single input.

In the information flow diagrams (Figure 3.2-1 and following) the following conventions will be used:

(1) Blocks (called nodes) with vertical sides represent instrumentation or groups of instrumentation of all degress of complexity. These include primary transducers up to, but not including, data recording.

(2) Blocks (called nodes) with slanting sides represent mental processes performed by the experimenter. It also includes any supporting teams or computing hardware which perform recording, storage, analysis or graphic display of the data as an aid to the experimenter.

(3) The block with curved sides or oval is the living organism comprising the subject of investigation. This may be a part of an organism, the whole or a group of organisms considered as an entity.

(4) Blocks or nodes are labelled N_x. Where N stands for a particular Nth loop around the flow diagram. There may be and usually are

several parallel loops. X stands for the particular mode, such as X = 7 is the Input Detector node.

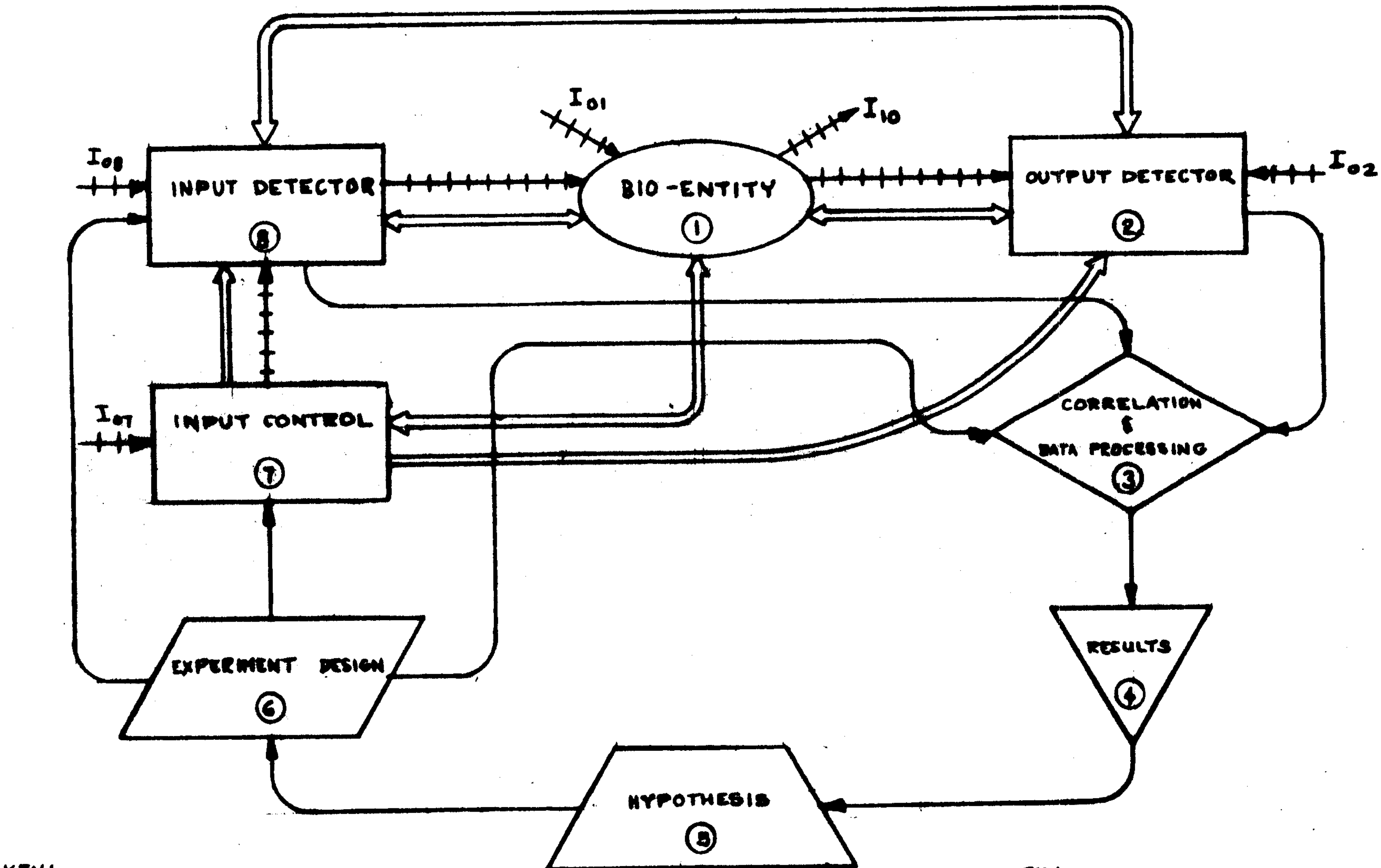
(5) The arrows with a single shaft and head are indicators of the flow of information around the diagram. They connect the interface elements of the blocks or nodes with each other. These arrows are labelled F_{ij}, the subscripts indicating the nodes which are connected. This information is wanted information.

(6) Arrows with a double shaft and head are interaction energy flow and indicate possible information flow in either or both directions between the nodes connected by them. These arrows are labelled I_{ij} indicating an interaction of i on j; a j on i interaction is labelled I_{ji}. This information is unwanted information.

(7) An "o" subscript on an arrow label indicates that the information source or terminus is unknown.

(8) Note that the information is carried in all cases by some form of energy, but that the form of energy is of material interest to the Experimenter only if the energy enters or leaves the bioentity. In these cases the information flow arrow is shown with cross bars. These indicate that the form of the energy or the way in which this energy is coded by the information it carries is of interest and value to the experimenter.

The Information Flow Diagram (Figure 3.2-3) shows a closed loop of information and an open loop of energy. Even a simple experiment could



KEY:

⇔ POSSIBLE BIDIRECTIONAL UNWANTED INFORMATION AND ENERGY INTERACTIONS.

NOTE:

INTERACTIONS ARE BETWEEN ENERGY SOURCES, CONTROLLERS AND DETECTORS.

Figure 3.2-3 Information Flow Diagram with Interactions - Stage II not be carried out if this closed loop were broken or if any of the nodes were missing. In a very simple experiment it may be hard to recognize each of the nodes shown, but whether implicit or explicit these nodes exist and a closed loop of information flow exists.

The question arises, where does an experiment begin? It may begin with any one of the nodes. For example, the cycle may be initiated with a living organism which has not previously been studied. Each of the nodes is then developed to produce a coordinated experiment. On the other hand, a new technique in statistical analysis may lead to an experiment which previously could not be performed or in which the results were not satisfactory. Recently many experiment cycles began with the hypothesis when the question "Do magnetic fields affect living organisms?" was asked. It really does not matter where in the cycle the experiment is begun. The cycle is started and as each node is added it must be compatible with all the other nodes in the cycle. A weak node in any part of the cycle will reduce the effectiveness and value of the other nodes. This cannot be avoided. The experimenter must keep in mind the strength or weakness of each of the nodes and adjust the others accordingly. If this is not done much time and energy can be wasted and lead to results which are either erroneous (without the experimenter knowing they are wrong) or at best, results which are of little value.

While an experiment may consist of one traverse through the experiment information loop it is more likely and more profitable to traverse the loop many times. Traversing the loop again and again is an effective replication of the experiment and can improve the confidence level of the final results. If on each traverse of the loop a change is made in one or more of the nodes, a new experiment is being performed which is then a part of a larger experiment. This is especially useful when the hypothesis is modified on the basis of the results of the previous traverse. Other changes may be indicated after a single cycle around the loop. Input and output instrumentation may be improved, input controls may be adjusted, more powerful statistical methods may be employed, computer aid in data processing may be added, efficiency and reliability may be obtained by reapplying the principles of experiment design, etc.

The value of using a diagram to aid in obtaining an overall picture of a biological experiment can be seen in Figure 3.2-4. This figure is the same as Figure 3.2-3 with the addition of lines showing interactions between various nodes. These interactions are possible flows of energy carrying information which is unwanted and may lead to erroneous inputs or outputs at the nodes, eventually leading to errors in the experiment. These interactions may occur in either or both directions and are shown as double arrows. They are not necessarily bidirectional. One or many may exist. It is not necessary that any exist, and it is the task of the experimenter to eliminate these interactions insofar as possible and be cognizant of and make allowance for those which cannot be eliminated.

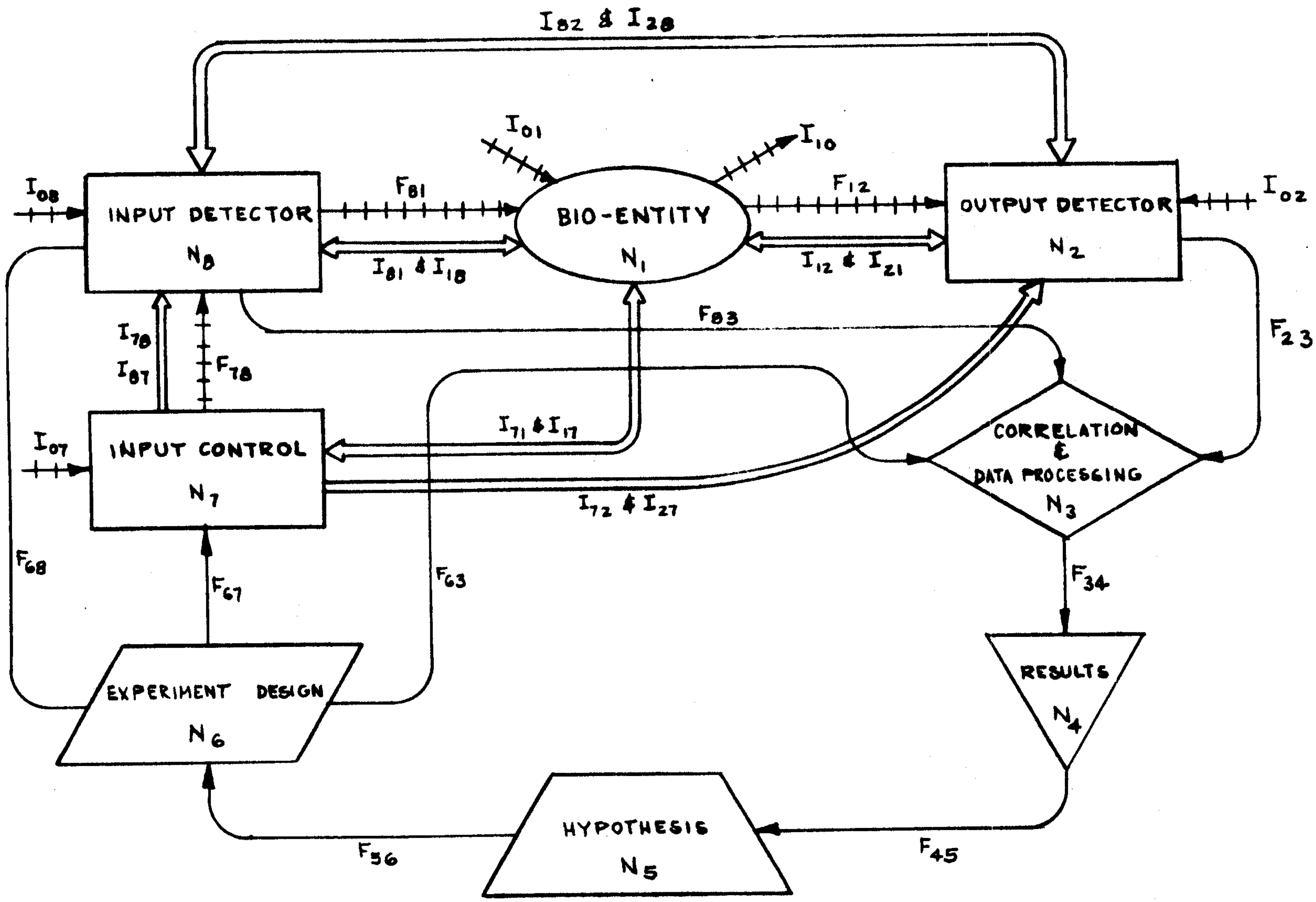


Figure 3.2-4 Information Flow Diagram with Labeled Interactions · Stage III

Possible interactions are shown between:

$1 \leftrightarrow 2$ Bioentity and Output Detector

$1 \leftrightarrow 7$ Bioentity and Input Control

$1 \leftrightarrow 8$ Bioentity and Input Detector

$2 \leftrightarrow 7$ Output Detector and Input Control

$2 \leftrightarrow 8$ Output Detector and Input Detector

$7 \leftrightarrow 8$ Input Control and Input Detector

In general

$N_x \leftrightarrow N_y$ an x node interaction with a y node in the same loop

Errors may occur in other ways such as interruption of information flow between, say, the input or output detector and the correlation nodes. This class of error generally can be traced to human or instrumentation failure and will not be discussed here. Other errors of a theoretical nature may occur in the incorrect formulation of the hypothesis, incorrect interpretation of the hypothesis or results, incorrect, or non-appropriate or incomplete application of mathematical, statistical or experiment design methods or techniques. These kinds of errors are of a different nature from the foregoing, do not involve the organization of the flow of information and energy and will not be considered in this discussion.

The greatest danger from the 6 pairs of interactions shown is that they may exist, produce erroneous results and yet the experimenter may be unaware of their existence. One of the values of the use of the diagram is that it makes these interactions explicit and exposes them to the experimenter, who, when aware of them, can then evaluate their consequences and take appropriate action.

It should be pointed out here that while in the diagram a single block each is shown for the Input Control, Input Detector and Output Detector, each of these blocks or nodes may represent a multiplicity of instruments and physical techniques in parallel. Interactions may take place between an input detector instrument measuring energy of one kind, say magnetic fields, and energy from this detector may cause an output detector measuring, say temperature, to give an erroneous reading. In addition to interactions of this type we may have interactions between two input detectors or two output detectors. Interactions of the first type may be represented as $N_i \leftrightarrow M_j$ where we have the i^{th} node of N loop interacting with the j^{th} part of the M loop. The second interaction may be represented by $N_i \leftrightarrow N_j$, interaction by two different nodes of the N^{th} loop. If each part of each node is considered as possibly interacting with each part of each other node as well as each other part of itself, then the total possible number of interactions is twice the number of combinations of the total number of parts of all nodes taken two at a time. If there are K total number of paths in say L nodes then the total possible number of interactions is:

$$I_{tot} = 2C_2^K = K(K-1)$$

Twice the number of combinations is used since an interaction may be from $N_i \rightarrow N_j$ or from $N_j \rightarrow N_i$, and these interactions may be totally different.

If, for example, we limit the interactions to Input Detector, Input Controls and Output Detector and have 4 of the first, N_8, M_8, O_8, P_8; two of the second, N_7, M_7; and three of the third, N_2, M_2 O_2, we have a total of 9 parts. The total number of possible interactions is:

$$I_t = 2C_2^9 = 9 \times 8 = 72$$

While it is extremely unlikely that more than a few of these interactions would occur in any well planned experimental setup, the example does show that even in a relatively simple experiment a large number of possible interactions exist and that a diagram showing them would make this clear. Such a diagram should be useful in both the design of the experiment and as an aid in finding any errors, should they occur.

A few examples of interactions which might occur are listed as follows:

Example 1. Bioentity → Output Detector, a $N_1 \rightarrow N_2$ interactions = I_{12} interaction. Here a chemical energy reaction of body fluids on the encapsulating material may eventually lead to failure of an implanted telemeter.

Example 2. Output Detector → Bioentity, a $N_2 \rightarrow N_1$ interaction = I_{21} interaction. Here an encapsulating material may have an unfavorable reaction on the tissue of the animal in which a telemeter is implanted.

Example 3. Output Detector – Bioentity, a $N_2 \rightarrow N_1$ interaction = I_{21} interaction. Here an implanted telemeter may be too large or too heavy to allow the subject animal to carry out its normal activity patterns.

Example 4. Output Detector – Output Detector, a $N_2 \rightarrow M_2$ interaction = I_{22} interaction. Here an activity detector may generate pulses which cause noise in a temperature detector producing an error in the temperature output. (An actual case which required considerable time and effort to solve.)

Example 5. Bioentity → Bioentity, a $N_1 \rightarrow M_1$ interaction = I_{11} interaction Here the activity of one animal may be heard directly (or indirectly from, say, electromechanical counter noise) and stimulate an activity response; i.e. one animal may entrain another.

These are but a few possible examples of interactions between the various nodes which exist as integral parts of a biological experiment.

Let us next consider the inputs and outputs of adjacent nodes. Referring to Figure 3.2-2 we note that between each node there is at least one arrow carrying information or energy and information. This arrow, which is the output of one node and the input to another, comprises with its terminations in these adjacent nodes, an interface. Some of these interfaces are of considerable importance. For Figure 3.2-2 the following interfaces F_{ij} can be described:

F_{12} - The Bioentity-Output Detector Interface

This is an organism-machine interface. Here the concept of the compatibility and suitability of the detectors and the environment to the physiological and morphological characteristics of the living organism is under consideration. It does <u>not</u> involve the physical suitability of the detector to the energy and information being detected.

F_{23} Output Detector-Correlation Interface

This is one of the most important interfaces existing in the biological experiment. It will be defined alternately as the machine-man-mind interface. It involves the communication process with all of the hard and software involved in compiling, translating and communicating the physical (electrical, mechanical etc.) digits or analogs to the man as meaningful information. This will be discussed more fully later.

F_{34} Correlation-Results Interface

This is essentially part of the F_{23} interface and will be combined with it in subsequent discussion.

F_{45} Results-Hypothesis Interface

This is a mind-mind interface. It consists of the mental processes of the experimenter involved in comparing the numbers obtained from correlation with the expected, predicted, or hypothetical numbers of the hypothesis. It is where the decision is made as to whether the hypothesis should be accepted or rejected. This decision depends heavily on the confidence levels which have been assigned to the results. Depending on what the decision result is, the experiment cycle will be terminated, or another trip around the flow diagram will be started. This is, a new or modified hypothesis will be evolved, and so forth.

F_{56} The Hypothesis-Experiment Design Interface

This is a mind-mind interface. This interface is where the transition in the thinking of the life scientist takes place between the generation of the theoretical biological question and the hard cold facts of how to perform an experiment which will confirm or refute the question posed.

F_{67} and F_{68} Experiment Design-Input Control Interface
Experiment Design-Input Detector Interface

This is another of the important interfaces with which the biologist is personally involved. It is the mind-man-machine interface. Here the experimenter determines the communication link between his wishes in the conduct of the experiment and their implementation. In other words, at this interface the biologist communicates with the instrumentation and thereby exercises control over the proceedings of the experiment.

F_{78} Input Control-Input Detection

This is a machine-machine interface and is of primary concern to the physical scientist rather than to the life scientist. Here, those energies which are controlled are connected to their monitors; feedback in the instrumentation sense may be employed if desired.

F_{81} Input Detection-Bioentity

This is similar to the F_{12} interface in that compatibility between the instrumentation and the living organism must exist. The requirements and care required in the design and application of the transducers are critical, especially in the requirements that the input is undistorted at this interface and that unknown or spurious energy sources generated at this interface do not contribute to the input of the bioentity.

F_{83} Input Detection-Correlation Interface

This is identical to the F_{23} interface except that the source of the information is an input to the bioentity rather than an output. It is handled in exactly the same way as the F_{23} interface.

F_{63} Experiment Design-Correlation Interface

This is a mind-mind interface. Here the benefits of good experiment design simplify in time and effort the task of the correlation. Also here, consideration of the confidence levels required in the correlation are reflected in just how the experiment design will be carried out. This is a most important interface and will be commented on later.

During the planning of a biological experiment each of these interfaces must be carefully considered. One aspect of the interfaces which is most important is that they be compatible with the nodes between which they operate.

Discussion of F_{23} Interface

This interface is important. If it is properly designed, it can reduce the time and labor required by the experimenter to obtain useful and meaningful results. If it is improperly designed, it can increase the time and labor required by the experimenter and possibly so cloud the data as to introduce serious confusion. Improper design may lead to a situation where no useful results can be obtained from the experiment.

One example of "interference" would be the case where the experimenter is not able to follow the course of the experiment and is not able to make decisions while it is in progress because he has committed it completely to automatic control. A second example might be where more data are taken than are necessary to obtain the desired results simply because it is easy to obtain a great deal of data by an automatic process. In this latter case the experimenter is simply snowed under an unmanageable mass of data and cannot see simple relationships which may actually exist

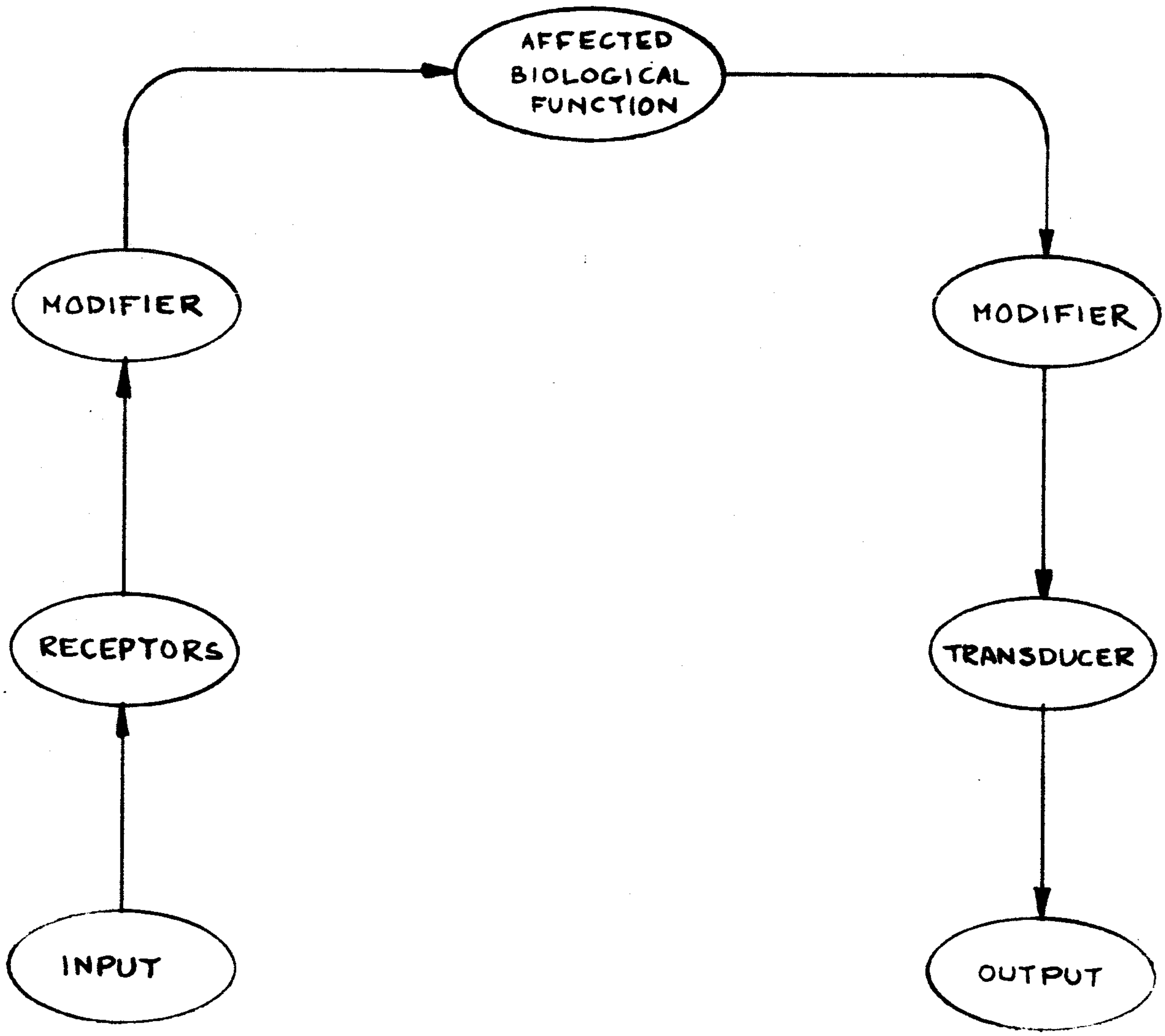
In summary, the three elements in an experiment which can and should be examined are: the possible choices of bioentity, the possible instrumentation choices and the man-machine, or experimenter-instrumentation interface. The experimenter will not be examined here, but is a worthy subject for examination.

3.3 DISCUSSION OF BIOENTITY NODE

Essentially, the bioentity is any living organism or collection of organisms examined as a whole, which has been, is, or will be, examined by the experimenter. There are many ways in which this whole field of biology can be systematized. The past methods may not necessarily be the best from the present-day point of view. At least they may not be best from a present-day experimenter's point of view. It may very well be that a better method of classification would be to use a classification based on the kind of response produced by the organism or the kind of stimulus given to the organism. A classification of this kind would be consistent within itself but would not necessarily directly relate to any other classification system. Such a classification is at present beyond the scope of this report but should be considered as a suitable subject for future study and development.

The biological entity may itself be diagrammed in order to help clarify the processes involved and to get a better picture of what goes on inside the entity. This should help the experimenter in the evolution and construction of the hypothesis for the particular experiment and in the actual experiment design. Further, it should be of assistance in the design of the instrumentation used in the actual processing of the experiment.

In Diagram I, Figure 3.3-1 we have the energy input as in the Information Flow Diagram. This energy input may be of any of a number of forms,



MODIFIER MAY INCLUDE BOTH AMPLITUDE AND PHASE MODIFICATION

Figure 3.3-1 Bioentity, Diagram I (Single Input) mechanical, electrical, chemical, light, heat, sound etc. and may carry information directly of value to the bioentity. Some kind of receptor or transducer in the bioentity coverts this energy into a form which is sensed by the bioentity. This energy change, chemical, mechanical or whatever, may then act upon some intermediate process or modifier in the bioentity. This intermediate process may or may not exist, but if it does, it in itself may have an important job to play in the path between input and output. The "signal" input, now changed possibly in both amplitude and phase, proceeds to the specific biological function which is affected. This often is the primary target of the investigation. What happens here is what the experimenter is interested in. Some change occurs in this function which then is passed on to (possibly) a second intermediate process or modifier. This second modifier can again introduce amplitude and/or phase modulation. The modifier then modulates some mechanism, chemical, electrical, mechanical, which produces the observed effect and indicates some energy change (the energy output) which can then be detected by the instrumentation of the experiment. This is a most simple and perhaps naive pathway from input to output in the bioentity, but it can be useful in that it forms a framework upon which the experimenter can build his picture of the workings in the bioentity. It can further be elaborated upon by the experimenter to obtain a picture which can become more and more detailed and hopefully, more and more useful.

In Bioentity Diagram II, Figure 3.3-2, we have one of these possible

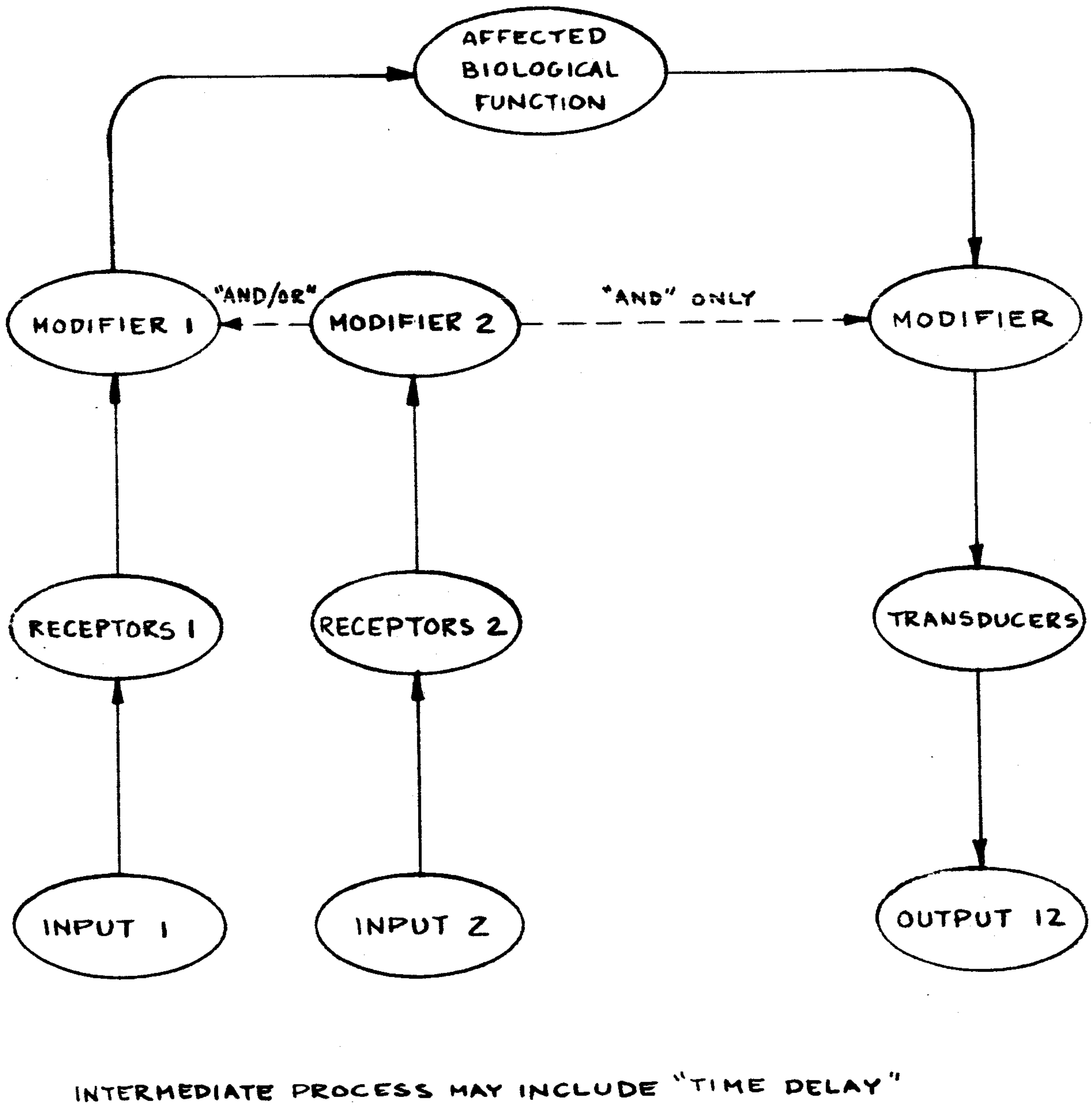


Figure 3.3-2 Bioentity, Diagram II (Two Inputs "And"/"Or")

elaborations. This consists of the addition of a second input. The second input may be effective through the modifier in such a way that both inputs are required in order for the biological function of interest to be affected. This is then an "and" effect requiring both inputs. On the other hand, it may be that one or the other is required to produce an effect on the biological function. In that case we have an "or" effect where either input may produce a change in the biological function. The inputs may be entirely different in character and be detected by the bioentity through different kinds of receptors. A different pathway for the second input may also be effective. This second input may go through (or be combined in) the modifier following the affected biological function. In this case only an "and" combination can occur since no output is produced if either input is missing. Because of the many kinds of inputs, receptors and intermediate processes possible, even the simple complication of the addition of one more input can produce considerable complication in the overall picture. As can be seen the resulting pathway can be fundamentally different yet look very much the same from the outside, that is, from simply an input-output observation. In this case it would be necessary to do further experiments in order to elucidate the pathways which are taken by the information and energy travelling through the bioentity. One way to do this (if physically possible), of course, would be to interrupt the possible pathway at various points in order to determine, if possible, just which path was being taken.

A further complexity should be mentioned here. This complexity is again one simple in concept, but one which can lead to great complexity in the overall picture; it is "Time Delay" or phase modification. In either Diagram I or II, or in more complex diagrams, the intermediate process may consist of a simple time delay where the input to the intermediate process is separated in time by a fixed or variable interval from the output. This may occur in either the intermediate process preceeding or following the primary biological function being affected by the original input. Possibly, this too can be investigated by severing the pathway at various times after the time of input and observing changes in the output.

A "time" effect of fundamental importance and at a higher level of complexity is that introduced by the concept of an "internal clock." Whether this clock is endogenous or exogenous can be for the moment disregarded (3-2, 3-7, 3-8, 3-9, 3-10). It can be considered as a variable time delay adding its input into the intermediate process before or after the affected biological function. It can, of course, be considered in itself as a primary biological function synchronized with an input and with or without a time delay, or it can be considered as an independent biological mechanism operating independently from all external inputs, but contributing a continually changing time function to be added in an "and" combination with outside inputs. It is not necessarily an end in itself, but may exist to control one or more primary biological functions (3-5, 3-6, 3-9).

Again, when we speak of a clock, we do not limit the discussion to a single timing mechanism. Many timing mechanisms may be operating in the bioentity independently, or in some phase-related synchronism to each other. A single clock is discussed only as a simplification. For a specific and particular case many clocks may be working together and appropriate diagrams of increased complexity may be drawn to illustrate the interactions between inputs, outputs, primary biological function and the clocks. The more complicated diagrams will be based on the simple diagrams shown in Figures 3.3-1, 3.3-2 and 3.3-3.

A listing or classification of the inputs or stimuli of interest to the biological experimenter and the instrumentation means of controlling and measuring these stimuli are of importance in describing the overall picture of the world of experimental biology. Such classification will be useful in the design of experiments and can be most helpful in the study of the feasibility of a Managed Energy Terrella or a "Stimulus Free" Volume. It will be the objective of this study to prepare such a listing. This listing should, where possible, be more than just a simple delineation. It should contain, where possible, as broad an evaluation of related instrumentation as is available and recommendations for their application as appear desirable or useful.

The output or responses, physical, chemical or behavioural of bioentities are numerous and varied. The instrumentation to measure such outputs ranges from the primitive to the most sophisticated, depending both upon the

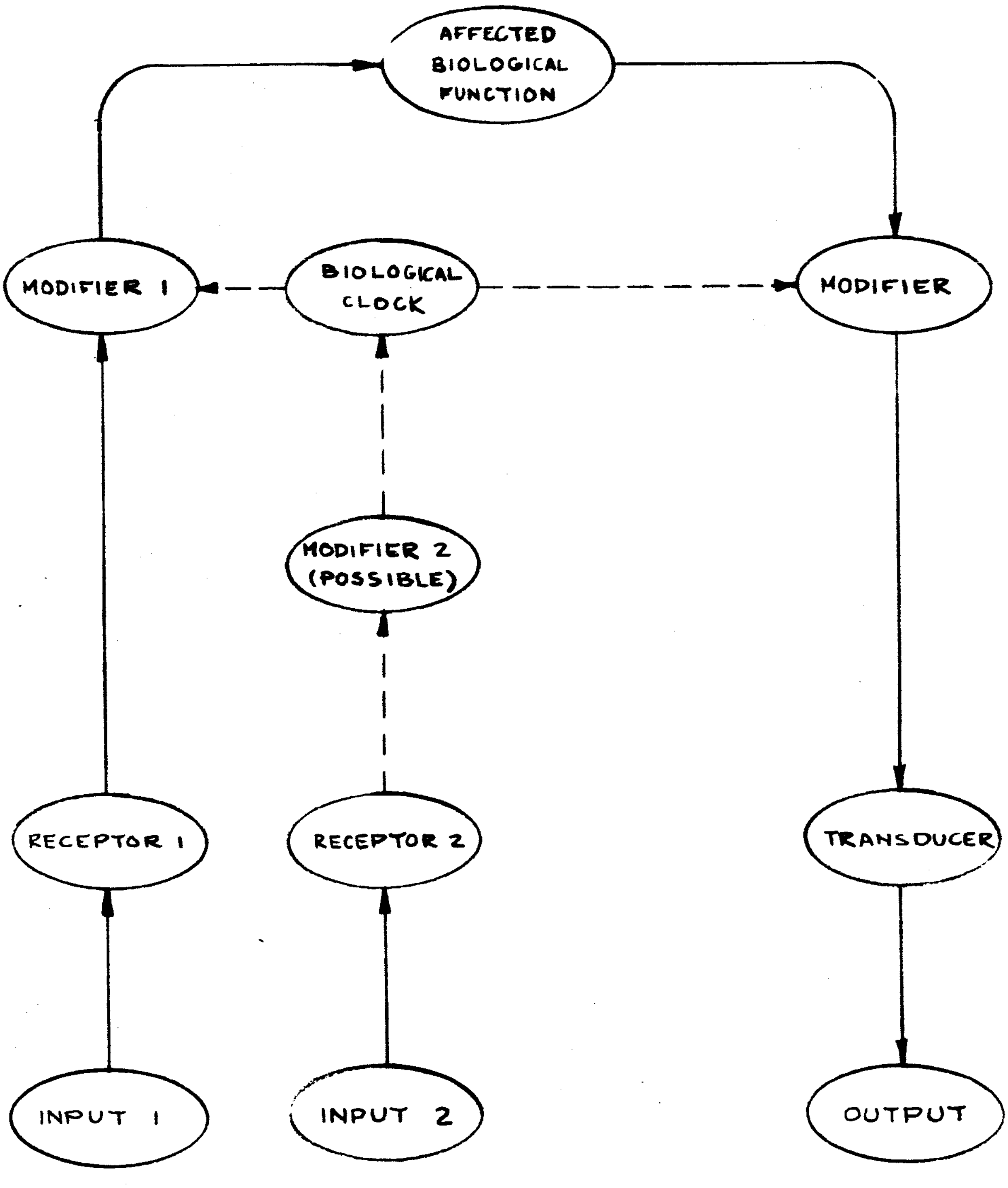


Figure 3.3-3 Bioentity, Diagram III (Clock Input)

outputs investigated and the accuracies required. Both the outputs and the instrumentation useful and necessary to measure these outputs should be listed or classified as an aid to the orientation of the biologist and the instrumentation designer. Again this study will attempt such a listing, classification and evaluation.

3.4 DISCUSSION OF INPUTS, OUTPUTS AND INTERFACES

As the accuracy of the data required in a biological experiment becomes greater and greater, as the number of measurements required for a given statistical effect to be clear becomes large, as the kind and number of measurements of input and output information becomes larger and more varied, and as the sophistication and elapsed experiment time becomes greater, it becomes imperative to the biologist that he obtain automatic data processors to help him collect and interpret his data. The man-machine interface can be broken down into three phases. One, the data recording or collection, and two, the data manipulation which consists of computing, and three, the data presentation such as graphic, numerical visual, or audible outputs. The automatic means whereby the data are presented to the experimenter in a form which will be readily understandable to him may be as simple as a meter or a counter and a pencil and paper, or as complicated as a large-scale data-recording device compiling data on magnetic tape, punch cards or punched tape. The interface is not yet complete, however, with only the inclusion of a data collection means. It is generally necessary to utilize some computation. This again may vary from the simple adding machine or slide rule, to a large-scale digital computer. Each method of data collection must be tailored to fit the particular experiment at hand. A fourth and most important element in the discussion of any data collection and manipulation system is the factor of time. The experimenter must decide, before the experiment is designed and before the system is designed, whether or not an on-line system is desired. An on-line system is one which can be thought of as recording and manipulating the data as they occur, or with a time lag which is inconsequential to the integrity of the experiment. An off-line system is one in which the data are accumulated as they occur and are then manipulated at the experimenter's convenience (usually at his inconvenience) at some later time remote from the actual progress of the experiment. The experimenter cannot follow the progress of his experiment with an off-line system. An additional on-line indicating system is required for this purpose. Generally speaking, most experimental configurations have some features of each category and are satisfactory. Completely automatic on-line systems are, without question, the most expensive and off-line, the least expensive. Because of the greater simplicity of off-line systems they are often more versatile than on-line systems. This is so because on-line systems are usually designed for a rather rigid set of conditions and for a particular, narrow range because of the large expense involved. This often proves to be unwise because the outcome of a given experiment cannot always be predicted in advance with sufficient accuracy to warrant the restrictions imposed by this procedure. The proper course of action is to design automatic on-line systems with considerable versatility so that as data are obtained from the system, the experiment can be altered to give the optimum ranges required and alternative methods of presentation as required. This course of action will probably be more expensive at first, but in the long run will be more satisfactory and will probably be more economical. For a rather elaborate and costly instrumentation assemblage as can vaguely be envisioned for a Managed Energy Terrella we can, however, definitely say now that a rather elaborate, versatile and costly data collection and manipulation man-machine interface will be required and should be planned.

In a fairly large scale on-line data computation system no specific recommendations can be made in regard to the data presentation without detailed information on the experiment involved. Several general recommendations should, however, be made at once. All the raw data (including monitoring of all inputs) should be available at one central console. These data should be available either continuously, or on command in analog (graphic plotting) form so that both the maintenance of equipment and the course of the biological experiment can be monitored and inspected visually. They should be on a time scale suitable to distinguish the rates of change expected and of sufficient amplitude to distinguish amplitude changes expected. They should be readily available for a reasonable past time so that visual comparison can be made on a past-present time basis. This may require several time bases. Further, they should be permanently recorded in numerical form, both time and amplitude, with sufficient accuracy to permit further or different analysis at a later date if desired. Automatic on-line computation may or may not be possible depending on the time base of the experiment. For example, analysis of a bio-rhythm may require a month's data for the final analysis, and it would be extravagant to make this automatic and on-line. However, the raw output data or partially processed data of the rhythms should be constantly available in graphic form to facilitate experiment management and monitoring.

3.5 DISCUSSION OF EXPERIMENT DESIGN

In a study of this kind where we are investigating the general problems of a biological experiment and their relationship to a Managed Energy Terrella we must take into consideration just about every conceivable source of energy which may act as an input to the biological system being studied or appear as an output. In some cases it will be possible, by means of knowledge previously obtained, to consider certain inputs as not having an interaction with others. In general, however, most energy sources must be considered as possibly evoking a response and as interacting with each other in the bioentity to evoke at least a two-variable interaction and possibly as high as three, four or more variable interactions. In biological experiments without prior experimental information, the magnitudes and phases of the interactions cannot be predicted. In fact, it is difficult even to surmise if these interactions are large or small, or even if they exist.

Clearly, there is a need for some method to test if interactions occur, or to effectively eliminate not necessarily the interactions themselves, but the consequences or effects on the outputs caused by the interactions. The latter is especially true if one or more of the interacting inputs is difficult to control.

The Need for Experimental Design

There are at least three compelling reasons for a general method or technique to evaluate and manage interactions resulting from several inputs to the bioentity.

The first is as mentioned above, that interactions do occur and are often unpredicted and unpredictable. Thus, we need a method of revealing interactions.

Second, we need a method, once these interactions are revealed, of measuring them and thus improving the metric basis of biology. Only when the interactions have been reduced to numbers can quantitative predictions in new situations be handled with any degree of confidence.

Third, we need a means whereby biological experiments may be carried on more ecomically. There are four aspects to the economics of a biological experiment. These aspects are: quantity of biological materials, quantity and quality of instrumentation, life and physical scientist (and their aids) man-hours, and total elapsed experiment time. All, of course, cost money. Economy in any one of these categories leads to a total overall reduction in dollars. At the present time much of the total cost of biological experimentation is being supported by the Federal Government (as is this present study). The purpose is to obtain biological knowledge. If the cost of obtaining a certain part of this knowledge is reduced, either it costs less "per unit knowledge," or we will obtain more knowledge per dollar. It is not likely at present, or in the foreseeable future, that we will run out of biological problems or the need for new knowledge. However, Federal budgets for obtaining this knowledge, while growing, are finite.

To get back to the several aspects of experiment economics, the availability or scarceness of biological materials is one determining criterion in the design of an experiment. Some biological materials are just not available in sufficient quantity to do the kind of experiment that the biologist would like to do. These experiments must be most carefully planned and executed to maximize resultant biological information. A simple example of this economic aspect might be the number of available astronaut-in-space hours.

The instrumentation and manpower available to design and build instrumentation is limited. Every biologist conducting a large experiment should have proper instrumentation and the aid of knowledgeable engineers to design it. There has been some tendency at present, however, to overemphasize this part of biology. The best instrumentation cannot assure a good biological experiment. Often the most expensive instrumentation is the worst instrumentation because it was not designed to be compatible with the experiment the biologist wanted to do. This is where experiment design should begin, before the actual equipment design. The instrumentation engineer and the biologist must, of course, be compatible and cooperate with each other and they must speak the same language. But, more important, the experiment must be designed prior to the instrumentation design so that the experiment can be properly designed in total. As far as we know, there is no simple, straightforward procedure to which the biologist can turn which will aid him in pre-instrumentation experiment design. However, there is available, but possibly not widely known, information to aid the biologist to design a highly efficient experiment.

Biologist-man-hours are, as instrumentation-man-hours, neither without cost nor unlimited. Any technique which will allow the biologist to do biology rather than "coolie work" will be economical and efficient. Experiment designor experiment planning can be this technique.

Elapsed time, today, is one of the most significant factors in planning anything, but is especially important in biological experiments. The normal life span of the bioentity, the normal gestation period, the normal hibernation period are but a few examples of time durations which cannot be shortened. From another point of view, because of the complex schedules of spacecraft launch dates, it is essential that certain biological information be made available for a flight in a shorter time than would normally be considered as convenient (3-11). These two requirements are inherently antagonistic and some biological experiments simply cannot be speeded up. However, with proper experiment design based on logical mathematical principles, many experiments can be completed in a significantly shorter time and thus meet tight ancillary schedules. In some cases this may have a definite corollary biological advantage. For example, in an experiment completed in a short elapsed time, ageing of the animals would be less and the uniformity of the population throughout the duration of the experiment would be improved.

In general then, good experimental design should, in many cases, enable the experimenter to achieve the desired results in a shorter elapsed time, resulting in several diverse advantages (3-12).

What Experiment Design Is

Let us first point out what experiment design is not. It is not the use of statistical methods or statistical analysis or collection of data. Statistical analysis is a way of dealing with data which exist and when these data are subject to unavoidable experimental errors, as most data are, there is no question of whether statistical methods can be avoided or dispensed with (3-12). They must be used and they must be used intelligently. Statistical analysis methods are an adjunct to Experiment Design, but are used <u>primarily</u> <u>after</u> the experiment is completed (3-13, 3-14, 3-15). But what should be done before the experiment is started? Hoel (3-16) points out: "too many experimenters do not seem to appreciate the obvious injunction that the <u>time</u> to design an experiment is before the experiment is begun." He also gives the opinion that: "Only rarely are the experiments that give valid conclusions as sensitive as they would have been if a standard statistical design had been employed." A design comes before the experiment; analysis follows it.

Neither is experiment design a haphazard plan or rule of thumb guess as to what is the best combination of factors or how many times the experiment should be repeated. It is rather, according to Davies (3-17) this: "A good experimental design is one which furnishes the required information with the minimum of experimental effort. To do this three things are required: first, the questions to be answered by the experiments must be correctly formulated; second, a correct choice of experimental method must be made in the light both of the accuracy required and of the various experimental pitfalls which are likely to be encountered; and third, the general pattern of the experiments, i.e., the number, spacing, and interrelation of the individual observations must be correctly chosen. It is with this general pattern comprising the number and interrelation of the individual items in a set of observations that the statistical theory of experimental design deals." He further states: "Using mathematical theory, it is possible to obtain measures of the quantity of information provided by the experimental arrangement, which can then be used to compare different arrangements to assess their suitability for any given problem." This is a clear and fair statement of what experiment design is, but it is still not the full story. Later he explains: "One of the main features of rational design, when properly carried out, is that it encourages the worker to make full use of all knowledge and experience at his disposal in order to assist him in planning his work." Actually, this can be put more strongly by saying that experiment design forces the worker to overtly make use of much of the knowledge and experience at his disposal which he otherwise may avoid or overlook.

Finney (3-18) puts it this way: "By the design of an experiment is meant: i) the set of treatments selected for comparison; ii) the specification of the plots to which the treatments are to be applied; iii) the rules by which the treatments are to be allocated to plots; iv) the specification of the measurements or other records to be made on each plot." ("Plot" in this case meaning the experimental specimen) Part iii) and possibly i) are generally the concern of the classical theory of experiment design. Each part, i) through iv), is important and must be carefully considered by both the experimenter and statistician (if other than the experimenter) in the overall plan of experiment design.

From a still different viewpoint of the same subject and with the same ultimate goal in mind, we find in Cox (3-19): "The requirements for a good experiment are then that the treatment comparisons should as far as possible be free from systematic error, that they should be made sufficiently precisely, that the conclusions should have a wide range of validity, that the experimental arrangement should be as simple as possible, and finally that the uncertainty in the conclusions should be assessable."

How can the experimenter aid the mathematician (if other than the experimenter) in producing a good experiment design? Adams (3-20) in an appendix on "how to ask questions" points out that to the mathematician: "Only the abstract structural properties of objects are of any real concern." The process of this abstracting is called "structuring" and helps to avoid the confusion and complexities of the technical jargon of a special field. He recommends: "By structuring the problem himself, the research worker can be prepared to give the statistician the information he needs in order to be of any aid to the research worker."

We find no argument with any of these viewpoints. Each emphasizes the main aspects of good experiment design, all eventually use the same techniques and mathematical formulations. These authors and many others referenced by them have provided the tools for the experimenter to use in preparing a good Experiment Design. But, the biologist has to dig out these techniques, he has to become familiar with them, and he has to become expert (or have available expert advice) in the application of Experiment Design techniques.

This is what hopefully has been made clear in this brief discussion: first, that good experiment design is as important in any experiment as the instrumentation; second, that statistical methods of data treatment are only a consequent part of the story in experiment design; third that good experiment design is economical and efficient in the utilization of instrumentation, men, materials and in the last analysis, money; and fourth, that the use of good experiment design techniques will provide the experimenter with an experiment which will produce data that are necessary and just sufficient to prove or disprove his hypothesis with a predetermined confidence in that proof (3-21).

3.6 DISCUSSION OF GRAVITY

On the surface of the earth, gravitational force is ever present and ever pervasive. It is a part of the normal environment of all living things. The earth's gravitational force is a simple, single example of the general and universal attraction existing between all material bodies in the universe (3-22, 3-23). The force of attraction between two masses m and m' separated by a distance r, K being the gravitational constant is

$$F = K \frac{mm'}{r^2}$$

If m and m' are in grams, r in centimeters, F will be in dynes and $K = 6.670 \times 10^{-8}$. In the case of the earth being one body and any material body on the "surface" the other body, then the force/gram will be 980.665 dynes as adopted by the International Committee on Weights and Measures (3-24). This defines the acceleration due to gravity as 980.665 cm/sec^2 and is commonly called one "g." This value is computed using an average earth radius. The actual value varies due to latitutde, longitude, elevation and time, as well as having local anomalies. These variations are small and are less than about ± 0.2% due to all causes. The total force on any material object is composed of this force plus the gravitational forces imposed by the sun and moon. These forces are also small and amount to less than ± 0.1% of the total force. They are generally termed tidal gravity and have periods which are a function of the rotation of the earth and the rotation of the moon about the earth. These forces cause land tides (as large as 7 cm) as well as ocean tides. While these variations are extremely small they have been shown to be significant in plant growth and animal physiology studies (3-25, 3-26, 3-27, 3-28). Although these variations cannot be shielded against, they can be accurately monitored with respect to amplitude and time by a tidal gravity meter (3-29, 3-30, 3-31). An additional force which is equivalent to a gravitational attractive force is that due to the earth's rotation and can amount to 0.3% of the total gravitational force (3-32).

None of these forces can be reduced by shielding or counteracted by static means. We can, however, effectively change the direction of the force on a material body which is non-spherically symmetrical by means of changing its orientation with respect to the direction of the gravitational force vector. In addition, we can obtain a more symmetrical change by obtaining a time average by cyclicly changing the orientation of a body with respect to this vector.

A third way of effectively changing the gravitational force is by adding or subtracting from this force an acceleration force due to linear or rotational motion. To all intents and purposes this is an effective means of changing the gravitational force.

No difference has ever been found between effects due to true gravity (attraction force between masses) and the similar or equivalent force due to acceleration (radial or linear)*. Thus, it would appear that gravitational and acceleration forces can be added vectorially. For example, by using a centrifuge to obtain 1 g radially, a net "g" of $\sqrt{2}$ g can be obtained on a subject place in the centrifuge (Figure 3.6-1).

Very reasonable values of "g" can be obtained by rotation in a centrifuge. For example the relative centrifugal force in g's (R.C.F.) is:

$$\text{R.C.F. (g's)} = 1.118r\, N^2 \times 10^{-5} \text{ (g's)}$$

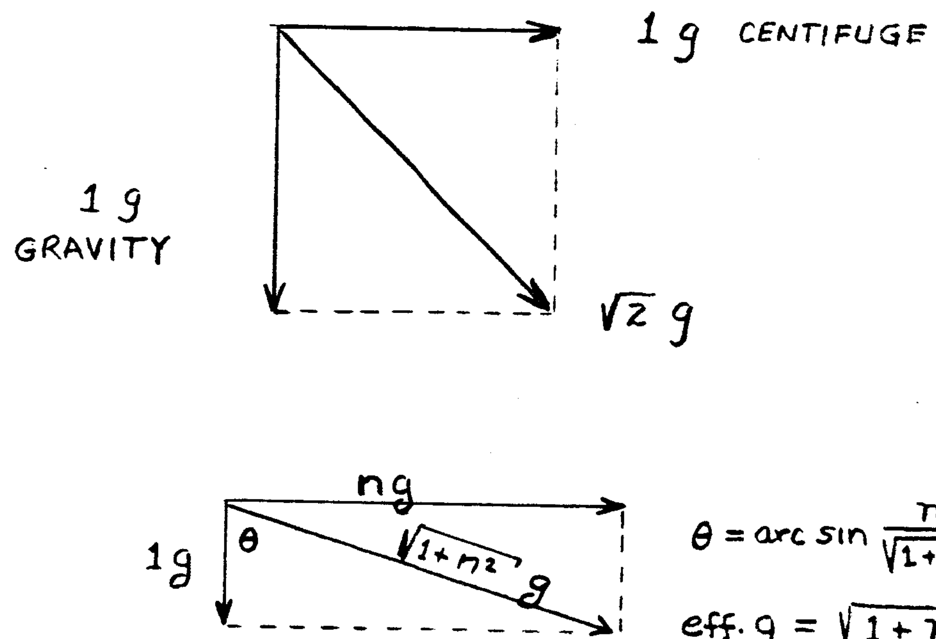
r = radius cm.

N = rpm

For typical values: $N = 100$ rpm and $v = 100$ cm (1 meter)

Then $\text{R.C.F.} = 1.118 \times 10^2 \times 10^4 \times 10^{-5} = 11.18$ g's

*The Eotvos experiment (1890) showed by using a torsion balance to compare the inertial (centripetal) forces arising from the earth's rotation with the gravitational forces due to the earth's mass that to 1 part in 10^9 the gravitational and inertial masses are equivalent. Dicke and Roll have recently (1963) repeated Eotvos' experiment with the same result to one part in 10^{11} (3-22).



$$\theta = \arc\sin \frac{n}{\sqrt{1+n^2}}$$

$$\text{eff.}\, g = \sqrt{1+n^2}\, g$$

Figure 3.6-1 Addition of Gravity Vector and Centrifugal Force Vector

And for N = 1000 $\simeq$ 31 rpm and r = 1 meter

Then R.C.F. = $1.118 \times 10^2 \times 10^3$ = 1.118 g's

There is no fallacy in using this method. There are, however, several precautions that must be observed.

A. Extension of Bioentity Dimensions

If the dimensions of the bioentity (plant or animal) are large in a radial direction, then the relative centrifugal force is not constant over this dimension but varies as the radius (Figure 3.6-2).

The ratio of the C.F. of the tip of the roots (R.T.) (2 m. radius) to the C. F. of the terminal bud (T.B.) (1 m. radius) is

$$\text{Ratio} = \frac{r_{R.T.}}{r_{T.B.}} = \frac{2}{1} = 2$$

If the rpm were such as to produce a radial g force of 10 at the root tip, it would be only 5 at the terminal bud.

B. The bioentity must retain its orientation with respect to the resultant g force. This can be effectively achieved mechanically by a hinge or pivot mounting of the sample (Figure 3.6-3).

C. Note also that the C.F. can be applied from root to tip or tip to root (Figure 3.6-4).

Another way in which the effective gravity on a plant can be modified is by means of a clinostat. Here the specimen is rotated about an axis which is at some angle greater than zero with respect to the earth's gravity vector. There is a large literature on the clinostat and a

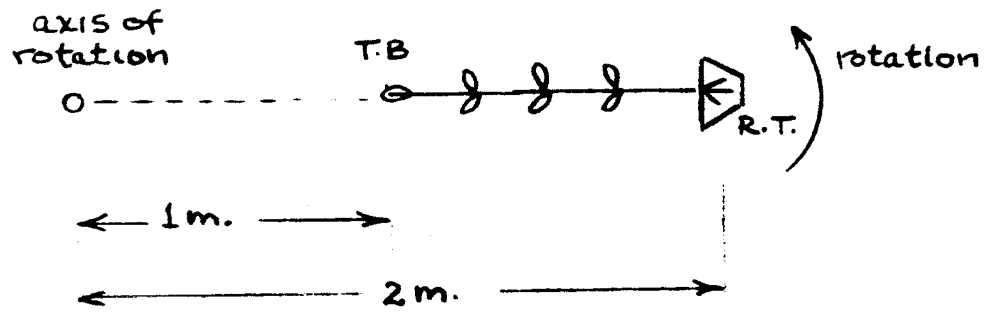


Figure 3.6-2 Variation of Centrifugal Force Vector with Radius

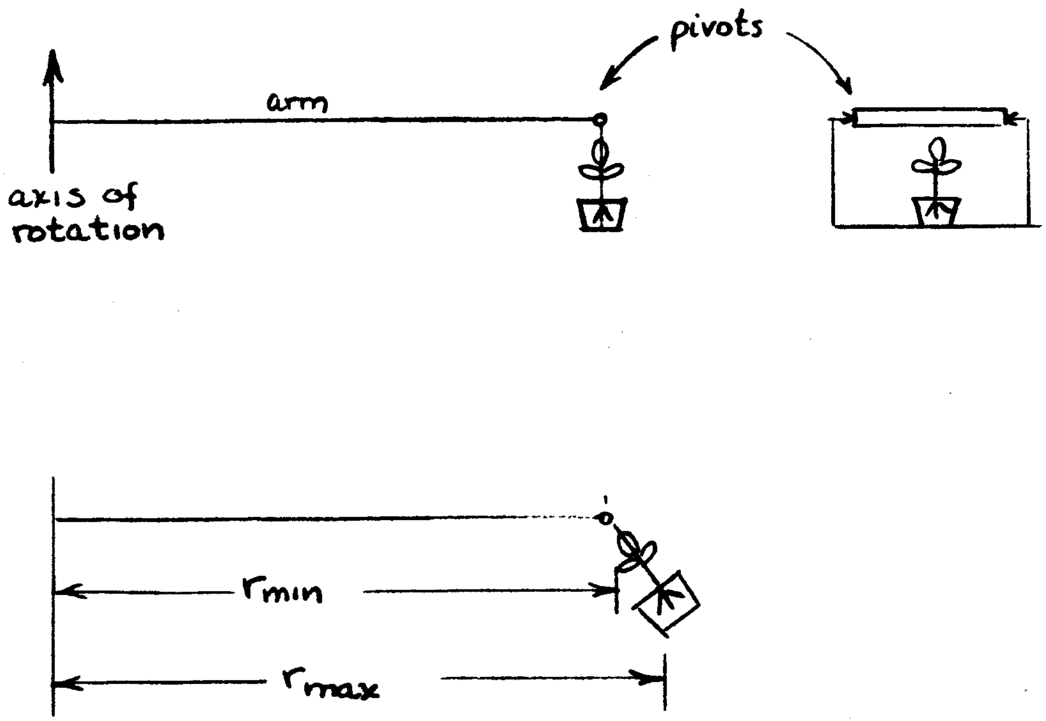


Figure 3.6-3 Resultant G-Force Vector Along Plant Axis

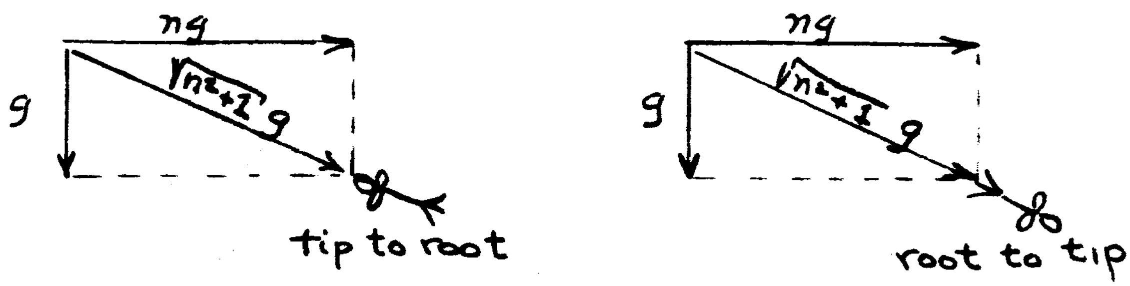


Figure 3.6-4 Orientation of Plant, Parallel or Antiparallel to Resultant Force Vector

number of experiments have been performed using it. This is a device whereby an effective fraction ($0 \leq f \leq 1$) of g can be applied to a plant specimen. A time average is required to obtain "0" g and change in the inclination of the axis of rotation to the vertical will produce a fraction of "g" between 0 and 1. It may also be used mounted on a centrifuge to obtain various g's from 0 to a small number. The important criterion which must be examined is the time average.

Figure 3.6-5 shows two typical versions of a clinostat to obtain "0" g. It is based on the assumption that the time the plant vector (V_p) (rotating with the plant) spends in its various relations with the gravity vector (V_G) averages to zero.

This is then the product of the time, times the projected value of the gravity vector V_G in the plant vector V_p. If the function of rotation is symmetrical with respect to amplitude about the time axis for the I and III and II and IV quadrants the average g force on the sample will be zero. A constant speed of rotation provides this symmetry and is generally used by experimenters because of the simplicity of its mechanization.

The requirements on the function of t are:

1) $f(t) = f(t \pm T)$

2) $f(t) = - f(t \pm \frac{T}{2})$

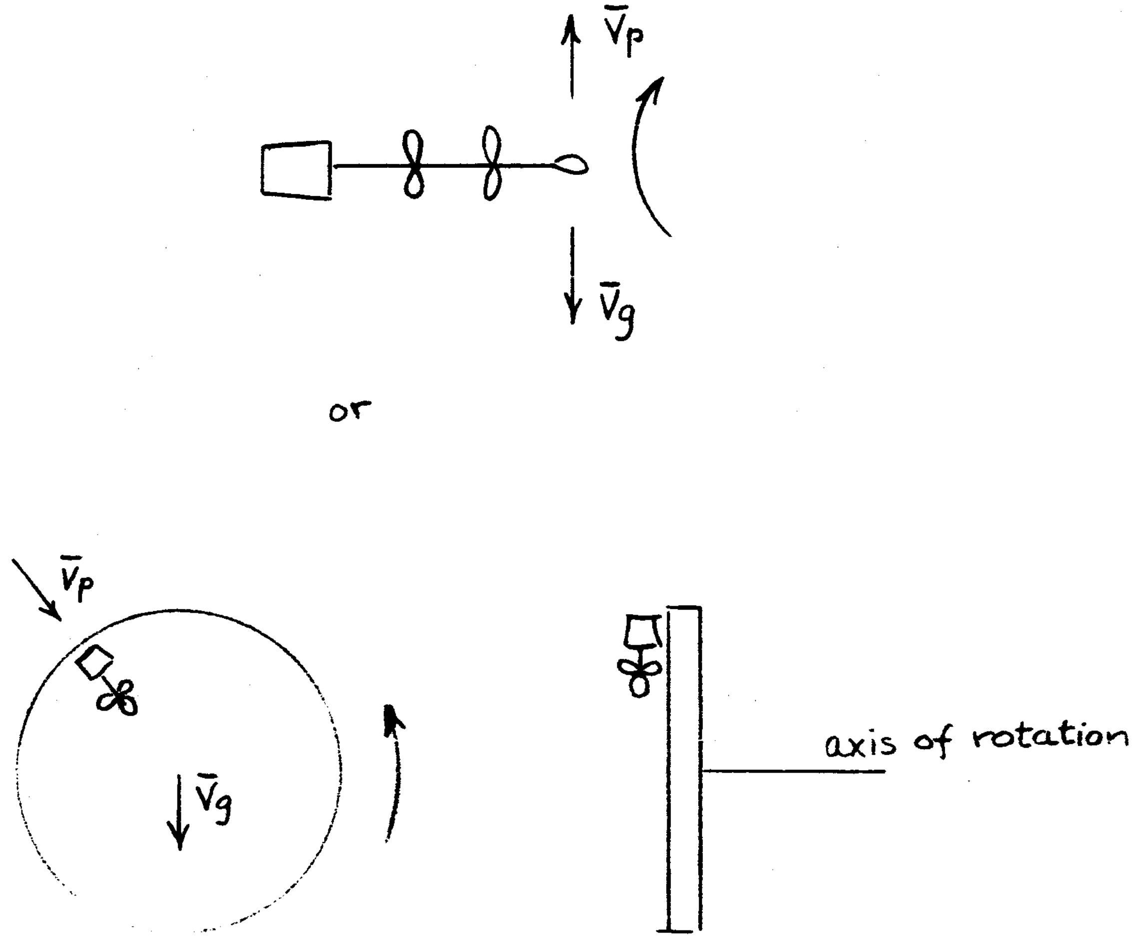


Figure 3.6-5 Clinostat Configurations

For example (Figure 3.6-6) the component of gravity (for uniform continuous rotation) directed along the plant vector from tip to root is

$$V_{plant \,||} = g \cos \theta$$

and across the plant from left to right is

$$V_{plant \perp} = g \sin \theta$$

$$V_{plant \,|| \text{ avg.}} = \int_0^T \frac{V_{plant \,||}}{T} dt = \frac{1}{T} \int_0^T g \cos \theta \, dt = \frac{1}{T} \int_0^{2\pi/w} g \cos wt \, dt = 0$$

$$V_{plant \,|| \text{ avg.}} = \frac{1}{T} \int_0^T V_{plant} \, dt = \frac{1}{T} \int_0^T g \sin 0 \, dt = \frac{1}{T} \int_0^{2\pi/w} g \sin wt \, dt = 0$$

In general this becomes for $\theta = f(t) = f(t + T)$

$$\theta = f(t) = f(t \pm T/2)$$

$$V_{plant \,||} = g \cos \theta$$

$$V_{plant \,|| \text{ avg.}} = \frac{1}{T} \int_0^T g \cos (f(t)) \, dt = \frac{1}{T} \int_0^{T/2} g \cos f(t) \, dt + \frac{1}{T} \int_{T/2}^{T} g \cos f(t) \, dt$$

$$V_{plant \,|| \text{ avg.}} = \frac{1}{T} \int_0^{T/2} g \cos f(t) \, dt + \frac{1}{T} \int_{T/2}^{T} g \cos f(t) \, dt$$

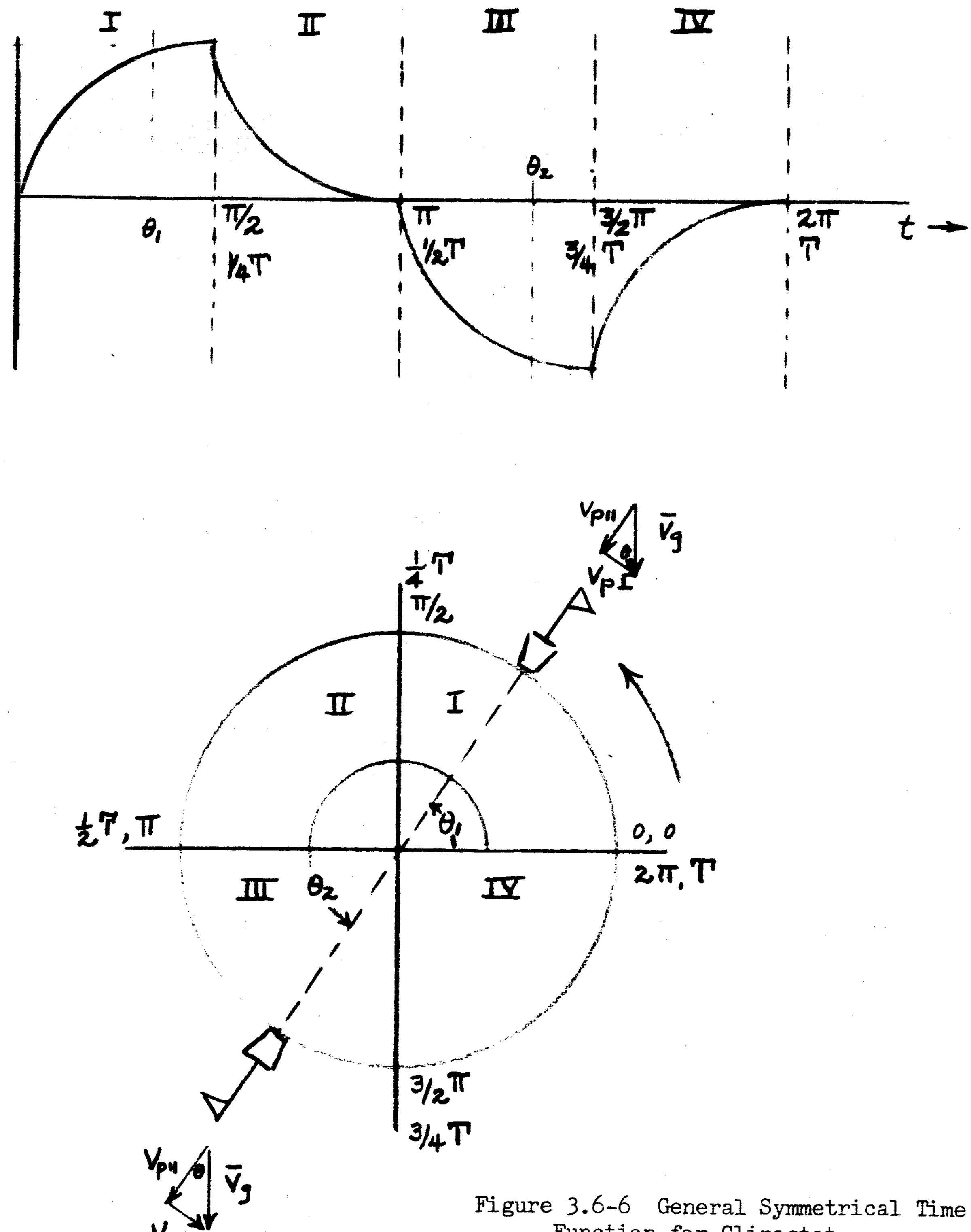


Figure 3.6-6 General Symmetrical Time Function for Clinostat

In second integral replace t by t - T/2

Then $$\int_{T/2}^{T} g \cos f(t)\, dt = \int_{0}^{T/2} g \cos f(t - T/2)\, dt$$

$$= \int_{0}^{T/2} g \cos(- f(t)\, dt = - \int_{0}^{T/2} g \cos f(t)\, dt$$

Then $$V_{\text{plant} \,||\, \text{Avg.}} = \int_{0}^{T/2} g \cos f(t)\, t - \int_{0}^{T/2} g \cos f(t)\, dt = 0$$

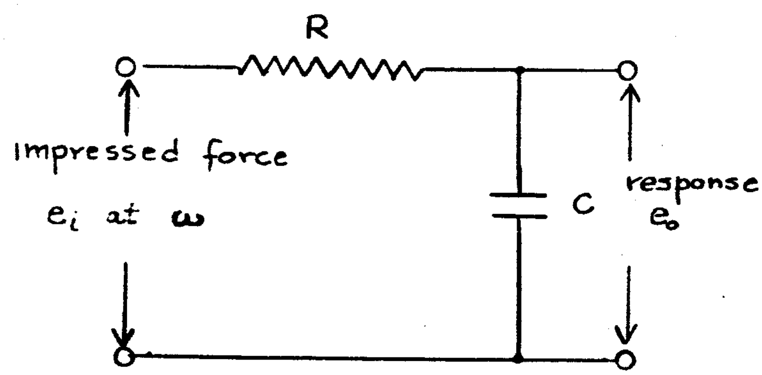
A most important factor must now be discussed. That is the time constant of the detector and/or the response mechanism in the bioentity (at the moment no distinction will be made between the two) to gravitational forces. While it is true that under the proper kind of rotation a clinostat can give a theoretical time average of zero g-force on the specimen, it is also true that the response will not be to the average but will be dependent on the time constant of the specimen. In effect, we are not applying a zero g-force but only an average g-force. What we are appplying is a varying g-force. For uniform rotation of the clinostat we have a sinusoidal force of Kg sin $2\pi ft$ where K is a fraction less than 1, and f is the revolutions per time of the clinostat.

The specimen itself has a time constant. It does not immediately respond (although it may immediately detect) a change in the gravitational force.

The response time or time constant τ_o is generally defined (for a first order lag system) as the time it takes for the system to come within $(1 - \frac{1}{e}) = 63.2\%$ of its final value in response to a step input or the equivalent; $\tau_o = 1/\omega o$ where ωo = the angular velocity and the response of the system is $\sqrt{2}/2$ and the lag is 45^o.

In brief, the faster the variation of the gravitational force and the longer the time constant of response the smaller this response will be to the variation in the gravitational field and the better the simulation of zero gravity we will have.

Suppose we have a biological specimen with a gravitational detector which is for all practical purposes instantaneous and a response mechanism with a one second time constant. Suppose further that we apply a variation of gravitational force of plus one to minus one to plus one at the rate of one radian per second. This can be accomplished by a vertical clinostat rotating at $f = \frac{1}{2\pi} \times 60$ rpm $\simeq 9.5$ rpm. If the response mechanism has a simple (first order) time constant, the response magnitude should be 71% of the infinite time response with a phase lag of 45^o. Suppose in the above example that the specimen response time (one time constant) is 10 seconds. The expected response magnitude in this case is approximately 10% of the long time response and lags the applied force by about 85^o. The analysis of a first order time constant system is as follows.



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Then $eo/ei = \left\{\frac{1}{1 + (RC\omega)^2}\right\}$ $\quad \angle \text{ lag } \theta = \tan^{-1} (RC\omega)$

If we define time constant of system as

$$\tau_o = \frac{1}{\omega_o} = RC \text{ then:}$$

$$eo/ei = \left\{\frac{1}{1 + (\tau_o\omega)^2}\right\} \qquad \angle \text{ lag } \theta = \tan^{-1} \tau_o\omega$$

This amounts to approximately 20 db of reduction in amplitude per decade.

ω/ω_o	Amplitude Ratio	Amplitude Ratio in -db	Lag (^{o})
1	0.707	3.01	45^o
10	0.099	20.04	84.3^o
100	0.010	40.00	89.4^o
1000	0.001	60.00	$>89.9^o$

Before using a clinostat with any particular biological specimen it would be well to determine the time constant of the specimen so that the relative response to the varying g force can be taken into consideration in the experiment design.

As was pointed out previously it is difficult to distinguish between the time constant of the detection of a change in gravity and the time constant of the response to a change in gravity. It might be useful to speculate that the mechanism of detection is the same for all ages and size of a particular plant but that the response mechanism will depend on the size only. Some differentiation could then be obtained by a series of experiments on just the response time of a plant. At present most of the experimentation is done on the response of a plant in a zero average field or the magnitude of the response in fields above and below the natural one g field rather than on time constants of response. A thorough study of the time dependence of this trophism could yield valuable information. This would be a proper study to be performed in a Managed Energy Terrell where other energy considerations would be eliminated, controlled or at least known.

3.7 DISCUSSION OF CORRELATION AND DATA PROCESSING

One important part of the problem of the correlation and data processing phase of an experiment is specifically the means or physical equipment used by the experimenter to aid him in arriving at meaningful numbers from the raw data.

This means using the discipline of mathematics and statistics and generally involves a considerable amount of computation of one sort or another. In very large and extensive biological experiments this can be handled readily by directly collecting the data by mechanical or electrical techniques suitable for direct input to a large scale computer. For many large scale experiments this has been carried out successfully and a considerable amount of study has gone into the details of the problem. On the other hand, for very small experiments a slide rule and a conventional desk calculator have proved sufficient. For some years now it appears that many experiments have been performed and are being performed which are intermediate to these extremes. This had led to several unfortunate consequences: one, that the data are insufficiently processed or two, that sometimes the data are totally wasted in that the processing is put off to a future time and is then forgotten. This is the direct result of either the lack of time and personnel to handle the data by conventional desk-top methods or the lack of availability of a large scale computer and programming personnel. The lack of planning sufficient funds for either of these, whenthe experiment was started, will produce the same results.

There has now appeared on the market a number of powerful desk-top electronic computers of reasonable cost. The computers can be operated in a short time by the experimenter or his staff and have many of the powerful features previously available only in a large scale computer. These computers range from the Dero (Sage I) at about $1,000 to the Linc (small scale computer) at $20,000. Many options as to input, output and programs are, of course, available in this range.

A chart of some of these electronic calculators is shown below.

Electronic calculator scorecard

Model	Registers (arithmetic, storage)	Register Capacity (bits)	Display	Sign display	Floating decimal	Round off & Drop off	Price
Friden 30*	4, 0	13	CRT	(−)	yes	yes	$1695
32°	4, 0	13	CRT	(−)			$1950
Monroe 2000	4, 0	16	tape	red ink	yes	yes	$2000
Olivetti 101	5, 5	22	tape	(−)	yes	yes	$3200
Dero (Sage I)	3, 1	20	lamps	(−)	yes	no	$ 995
SCM 240*	3, 3	12	CRT	(+ −)	yes	no	$2195
240SR°	3, 3	12	CRT	(+ −)			$2395
Victor 3900	3, 3	20	CRT	(−)	yes	yes	$1800
Wang 300*	4, 0	10	nixie	(+ −)	yes	no	$1690
310°	4, 0	10	nixie	(+ −)			$1895
320'	4, 0	10	nixie	(+ −)			$2095
Wyle Scientific	3, 3	24	CRT	complement for minus	no	no	$4700

*business calculator °statistical calculator, includes square root
'scientific calculator, includes log x and e^x

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A Wang Laboratories (Tewksbury Mass. 01876) computer called the Loci-2 ($4,750) has many valuable features. One of these is that programs for calculating a huge number of functions can be conveniently and quickly carried out by means of punched card programs. Many of these programs are available from the manufacturer and are known in the computer trade as "software." In the Loci-2, even the problem of punching the program into the card has been simplified, prescored cards can be punched with a pencil tip. A desk-type computer of this kind can perform the work of several laboratory assistants in a fraction of the time and a fraction of the cost.

Another desk-top computer of a similar nature is the "Mathatron" (Mathatronics, Waltham, Mass. at $3,500). Options with the Mathatron are printed or punched paper tape output and punched paper tape input. Also available is interface instrumentation which will allow this computer to be used "on-line, immediately computing results from new data. Typical of some of the programs for this computer are: solution of simultaneous equations, linear correlations, standard deviations, correlations and distributions. Both the Loci-2 and the Mathatron maintain 8-digit accuracy and perform calculations at the rate of approximately 100 per second.

The Linc Computer and the PDP-6, 7 and 8 are approximately 4 or 5 times the cost of the above-mentioned computers. These are essentially small (2 desk) size complete computers made by Digital Equipment Corp., Maynard, Mass. The Linc was designed for the biological and medical research worker for use in his own laboratory. Among the many options and features of this computer are the two outstanding features of input control and on-line data collection. Essentially this small computer can, (when properly programmed by the experimenter) and with the aid of Input and Output Detectors completely perform a biological experiment. It will thus, with a bioentity, complete the information flow loop. It can even be programmed to compare results with the hypothesis and change its program to traverse the Information Flow Diagram again and again. Of course, there is no magic involved, it can only do what it has been programmed to do, but because of its great power and versatility the biologist can spend his time doing biology rather than data accumulation and calculation.

The life scientist today can no longer afford to continue making calculations by means of conventional desk-top methods when electronic aids of this power are available at such reasonable costs.

3.8 DISCUSSION OF MAGNETISM

On the earth, the magnetic field is a pervasive vector. It exists everywhere and remains readily discernible unless one moves considerably more than ten earth radii from the planet.

While the vector direction and amplitude are generally known for any given location in latitude and longitude, these parameters are by no means fixed in value. They are subject to influences arising from deep within the earth itself, local geological change, man-made causes and the sun.

Since change in the field strength and direction is sufficiently great so as to be easily detectable with relatively crude instrumentation (the simple magnetic needle), we must assume the possibility that living systems may also be capable of such detection and may even be affected in their operational activities by such changes. The foregoing may be further extended by considerations of effects of magnetic fields, <u>however stable</u>, on living systems. While such hypothetical susceptibilities may appear to be of primary interest to those workers in the areas of biological rhythms, growth control and animal migration studies, one cannot at this juncture, limit the potential of such effects in any way. We just do not know enough to do this.

What are the levels and directions of earth fields? How do these compare over the earth's surface? What sort of variation may one expect to experience at a given locale? If one wishes to control these fields for purposes of biological research, can such control be accomplished with accuracy and on a dynamic basis? What must one expect in the way of magnetic fields if an experimental payload is placed in orbit? etc.

3.8.1 PERTURBATIONS IN THE MAGNETIC FIELD

These questions and many more are directly pertinent to the MET concept. Certainly since the magnetic field is not constant on earth and because it exists at all, it represents an energy stimulus to be controlled or nulled and/or monitored in the consideration of the biological experiment.

A brief review of the situation is in order. If one were able to remove oneself to a point distant from the earth and then given a special ability to see magnetic lines of force, one would see (ideally) approximately what is depicted in Figure 3.8-1. The earth appears to be a magnet with poles approximately at the poles of planet revolution. In actuality, the magnetic poles are located within the Arctic and Antarctic circles close to 71°N., 96°W., and 73°S., 156°E. of Greenwich, respectively (3-33). Were the magnetic poles congruent with the ends of the earth's axis of rotation, which are the geographic poles, they would be located at 90°N., 0°W., and 90°S., 0°E. of Greenwich.

Interestingly, it has been hypothesized that the virtual magnetic poles migrate with time. If this were the case, there would be little question

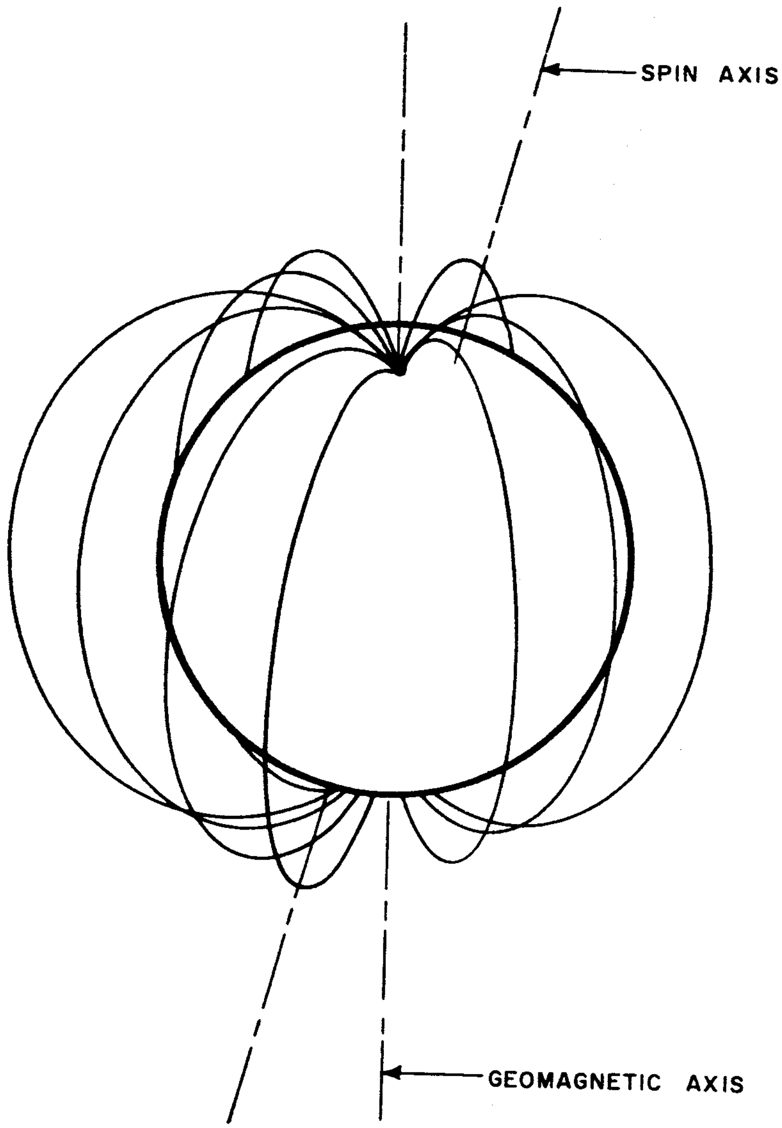


Figure 3.8-1 Earth Field (Idealized)

that such polar motion implies a cause for variation in the magnetic vector direction and magnitude over the entire earth. An interesting report by Watkins (3-34) discusses the possibility of just such occurrences along with a number of opposing theories.

Based on man's experience with compass navigation over the past centuries and an examination of the yearly charts published by the United States Hydrographic Office and Geodetic Survey plus the foregoing comments, it is amply clear that not only do magnetic "meridians" not lie congruent to the geographic meridians, but that they vary with time. Further, these magnetic lines bear no resemblance whatever to the great circles of geography, for because of local geological anomalies and diurnal, weekly, monthly and secular variations, the weaving lines of magnetic direction are subject to constant change.

In addition to these variations, we are subject to the influence of the sun. Figure 3.8-2 shows in idealized form an interesting situation wherein the solar wind affects the magnetosphere (3-35) (3-36) (3-37) and is consequently reflected to some extent in local effects over the earth.

The details of the measurement (3-38) (3-39) of the causes of the earth's field and its variation and the hypotheses involved (3-40, 3-41, 3-42, 3-43,3-44) are fascinating. However, they do not specifically relate to the problem at hand. Our interests lie with the prospective determination (insofar as possible) of the changes to be anticipated on the earth and methodology

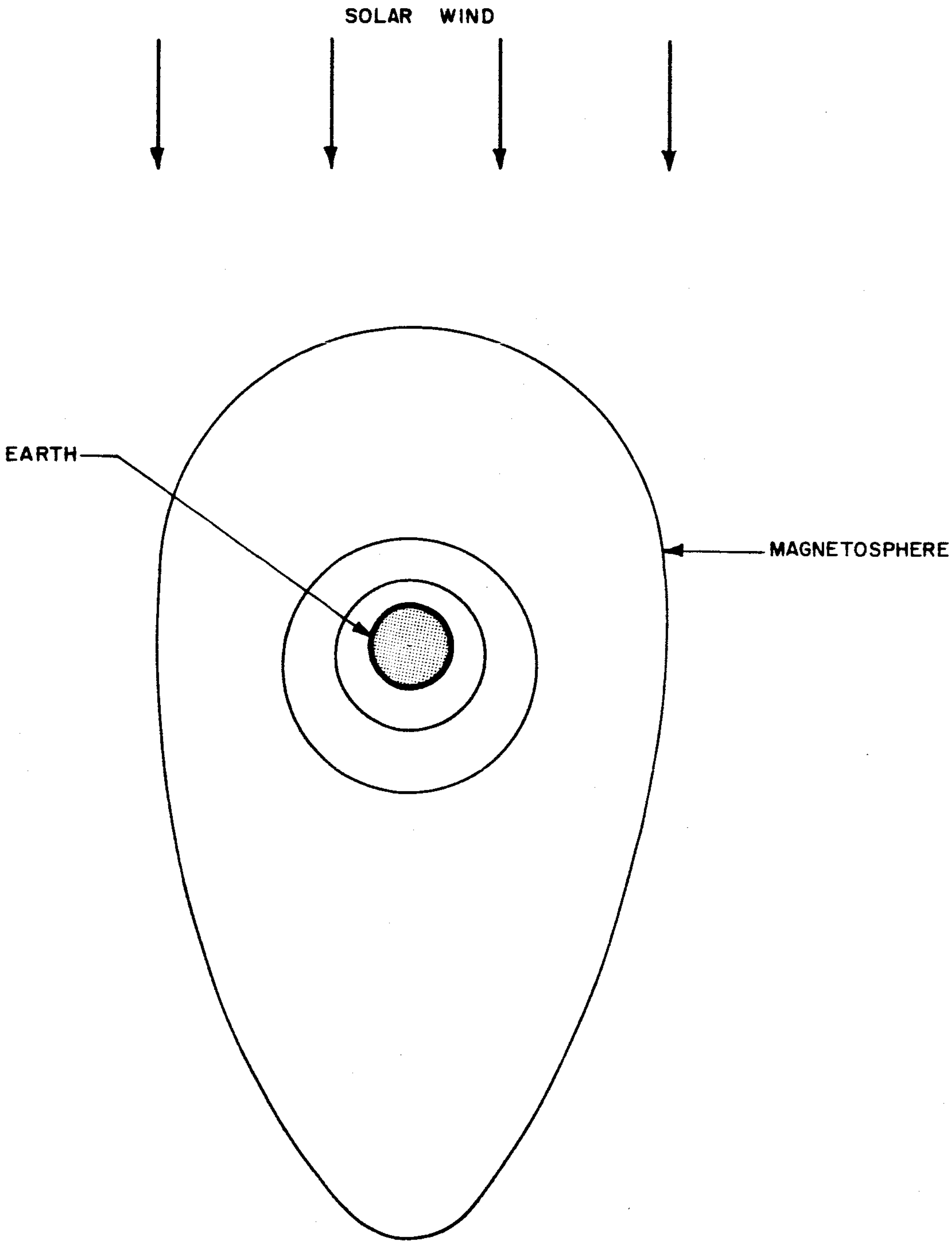


Figure 3.8-2 Magnetosphere Slip Streaming

for their control and measurement as these relate to the biological experiment design.

To pursue our study further, let us review some of the data available to us. In the first place, the magnetic field at any location on earth is a vector and is usually described by two components: the vertical, called Z, and the horizontal, called H. The total, or resultant field vector is called F. The relationships involving various specific measurements reported are illustrated in Figure 3.8-3 (ibid). The unit of magnetic field intensity measurement is the oersted which has the dimensions as follows:

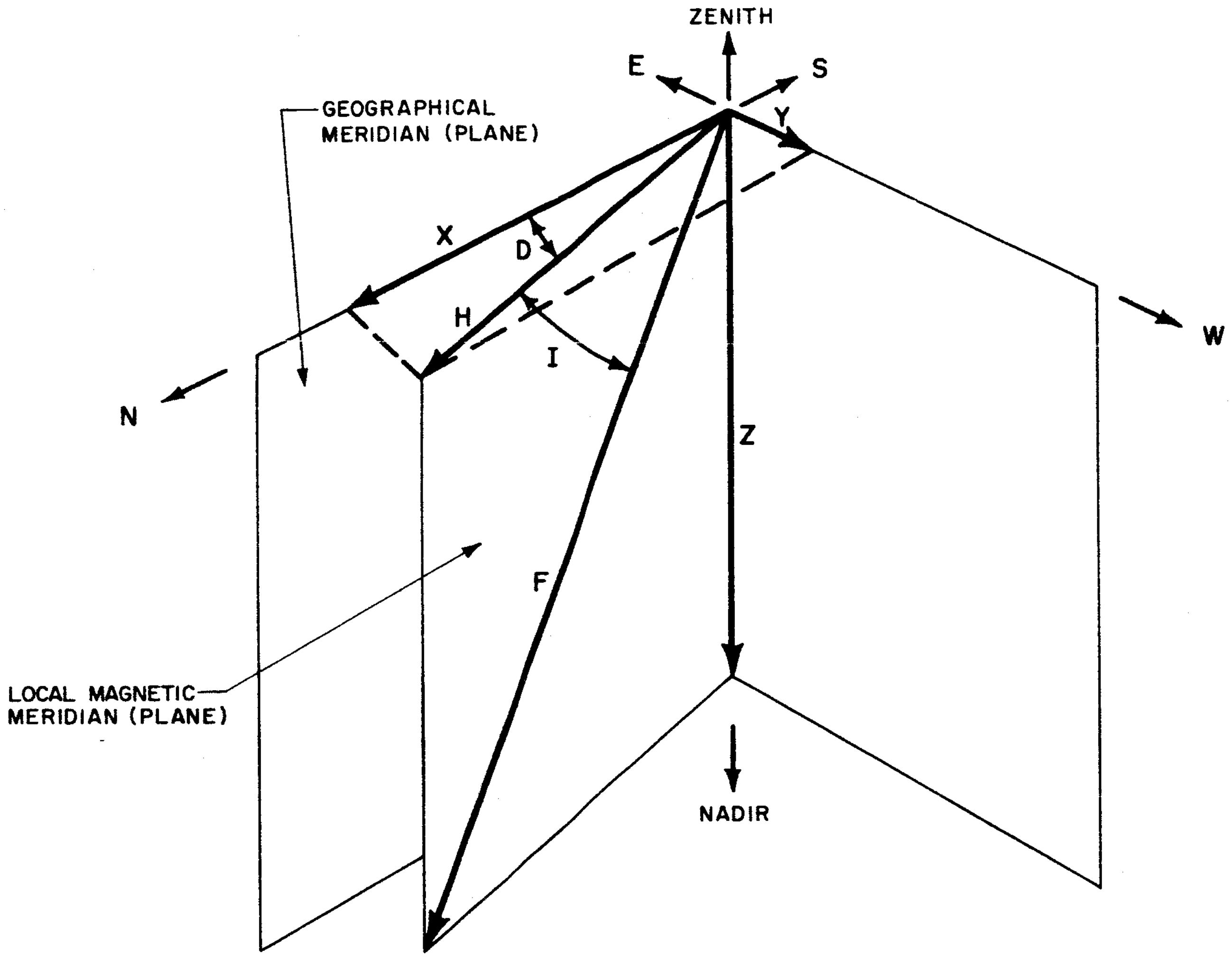
$$1 \text{ oersted (electromagnetic cgs unit)} = \mu^{-\frac{1}{2}} \text{ grams}^{\frac{1}{2}} \text{cm}^{-\frac{1}{2}} \text{sec}^{-1}$$

$$\text{Gamma } (\gamma) = 1.0000 \times 10^{-5} \text{ oersted}$$

The magnetic field intensity is that field which exerts a force of one dyne on a unit magnetic pole. In more conventional units 1 ampere turn per centimeter = $\frac{4\pi}{10}$ oersted.

The name oersted was given to the unit of magnetic field intensity, formerly known as the gauss, by the International Electrochemical Commission in 1930.

From a physical viewpoint, the gauss is defined as the cgs emu of magnetic induction (flux density). It is equal to 1 maxwell/cm^2. It has such a value that if a conductor 1 cm long moves through a magnetic field at



$F = H \sec I$	WHERE	D =	DECLINATION
$X = H \cos D$		H =	HORIZONTAL INTENSITY
$Y = H \sin D$		Z =	VERTICAL INTENSITY
$Z = H \tan I$		X =	NORTH-SOUTH COMPONENT
		Y =	EAST-WEST COMPONENT
		F =	TOTAL INTENSITY
		I =	INCLINATION

Figure 3.8-3 Components and Declination of Earth's Magnetic Field

a velocity of 1 cm/sec. in an induction mutually perpendicular, the induced emf is one abvolt (3-45). Note that one abvolt = 10^{-8} volts (mks).

Present literature uses the terms "oersted" and "gauss" interchangeably. In view of internationally agreed definitions such usage is not correct. However, to prevent confusion, we will use the term "gauss" instead of "oersted." This interim decision is made because so many of the important references listed use "gauss."

A short review of typical world survey plots such as that illustrated (year 1945) in the reference to Heppner (ibid) shows that total field intensity (F) ranges as low as 0.25 gauss to a maximum of about 0.7 gauss with North America experiencing field levels between 0.5 and slightly more than 0.6 gauss. Levels as low as 0.25 gauss show up at the middle east coast of South America. Information is available which indicates the order of magnitude of a variety of variations in local fields. Keeping in mind the fact than an average total field value is 50,000 γ (0.5 gauss) we find that isoporic* charts are constructed for each of the field elements and the total field. A description of procedures will be found in Reference (3-46). A typical world chart shows contours indicating changes of -40 γ/year in the mid-southwest of the United States, and about 20 γ/year across the northern part of the country. Unfortunately such charts are not specifically useful at precise locations

*Charts showing contours of equal annual change other than those at which observation stations have been established. In this regard, the distribution of geomagnetic observatories over the earth leaves much to be desired. Annual changes in contour do not appear to be exceeding about 120 γ/year at present. A number of studies, however, have indicated that secular changes may have been such that the vector direction of the earth's field may actually have reversed a number of times in the distant past. For this to have occurred, the field must necessarily have passed through zero in magnitude (3-40 ibid). The importance of this conjecture resides in its significance to those workers studying the origin of life on the earth. Based on present knowledge, an earth with a zero magnetic field (however transient) would be exposed to a deluge of high energy solar and cosmic radiations which could profoundly affect hypotheses dealing with life origin.

Continuing our review of field variations let us now consider local changes occurring in the periodicity range of less than a second to the order decades (3-47). At the Kakioka Magnetic Observatory, Kakioka, Japan, geomagnetic observations are published for installations at Kakioka and Memambetsu (3-48). Induction magnetometers there are able to detect variations as small as 0.2 γ/sec. with a frequency response on the order of 2 seconds. Variations in this range are shown to have been detected and to occur. Green, List, Zengel (3-49), present data indicating that the average quiet day diurnal variation in the total magnetic field at 40^{o}N. magnetic latitude is about 20 γ with a minimum at 1200 hours (noon).

Nighttime micropulsations on the order of 0.6 γ with a periodicity of about 60 seconds were measured at Dallas, Texas, and somewhat smaller pulsations with a periodicity of 25-35 seconds during the day. "Pearls," which are micropulsations in the magnetic field and which evidence a characteristic "beating" envelope occur in the frequency range of 0.3 to 3.0 seconds and are usually less than 1 γ in peak-to-peak range. These pearls also show up with a periodicity of about 25 seconds after the sudden commencement of a magnetic storm. It is pointed out the power density distribution versus frequency for the geomagnetic field is extremely low at relatively high frequencies ($\approx$1 cps) and rises sharply with falling frequency.

Low level, short period variations in the geomagnetic field with a seasonal frequency were reported by Okhocimskaya (3-50). He points out that the annual curve for these disturbances is explainable in terms of the zonality of sun-spot distribution plus characteristics of the mutual inclination of the solar and terrestrial equatorial planes.

Attempts have been made to study the variations of geomagnetic activity with lunar phase (3-51). These workers analyzed 21 years of data in their statistical search. Their results indicate that a broad maximum of geomagnetic activity ($\Delta \approx 4\%$) begins about a half day after full moon and lasts for about seven days; a broad minimum of activity ($\Delta \approx 4\%$) exists for about seven days preceding full moon; there is nothing at new moon but random fluctuations. These same authors report a private communication from Shapiro and Ward indicating the application of power spectrum analysis to over 80 years of data in a search for enhanced activity as a function of frequency. This communicated information indicates a peak at near 27 days (solar rotation period) and a smaller peak near 29.5 days (the lunar month). Shapiro and Ward consider the physical reality of the 29.5 day peak to be uncertain at this time.

Kalashnikov (3-52) has related certain perturbations in the geomagnetic field to meteors. He reports variations of as much as 6 γ which he indicates to be related (in this case) to the time of Leonid maximum.

The sun's general field is estimated to be about 1 gauss (3-53). The stronger sunspots may produce flares and evidence fields as large as 5000 gauss. Interplanetary fields indicated on the basis of satellite and space-probe measurements are of the order of 2 to 10 γ. Observations on the geomagnetic field at satellite altitudes will be found in (3-54).

Now let us consider briefly the perturbations which occur during magnetic storms (3-55). Such storms appear to have phases: there is usually an initial increase in field, followed by a much larger diminution which attains a minimum about 15-20 hours after the beginning of the storm. These sequential variations are called the "main phase" of the storm. It is followed by a gradual recovery phase occurring over a period of one to several days.

Interestingly, the greater the intensity of the storm, the more rapidly are the phases completed. Apparently these storms are highly variable, in that the initial phase may appear alone with no subsequent main phase, or the onset of the storm may be so gradual that an initial phase cannot be identified. The equatorial range of horizontal field intensity H is often used to indicate the general intensity of the magnetic storm. Such intensity variation ranges for great magnetic storms over the past century fall between 250 and 4200 γ.

The foregoing brief remarks are of interest because they illustrate the complex variety of periodic and apparently aperiodic perturbations to which the geomagnetic field is subject. Since living systems, as we know them, are subject to these same fields and the changes in them, there is no alternative to their recognition as potential stimuli. In this latter regard a number of workers have addressed themselves to the study of magnetic field effects on living systems (3-56,-57,-58,-59,-60)

3.8.2 MEASURING THE MAGNETIC FIELD

Since our primary interest resides in the biological experiment we may now address ourselves to the problems of control and measurement of the magnetic field in which the bioentity of interest is immersed. It is perhaps simplest to begin with measurement instrumentation.

A large number of instruments are available commercially at the present time. Costs for these devices are in the range of $400 to more than $4,000. In all cases the instruments involved have at least an indicating pointer (meter) analog output. In the higher price range, one is often able to obtain simultaneous recorder output signals. This is to say that a signal is made available which is capable of suitably deflecting one of a number of commercially available ink writers or similar recorders.

Instrument sensitivity in this cost range runs from a barely readable 10 γ least count to a usable 1γ, least count. Most of the devices, with the exception of those at the upper cost levels have only dc or relatively low frequency response. While much in the earlier paragraphs of this report tends to indicate that natural magnetic field perturbations are primarily of the very low frequency type, the researcher is, unfortunately, usually a victim of quite another additional problem: man-made perturbation. Man-made devices produce magnetic fields of considerable potential consequence to the biological researcher in the frequency range from dc to higher than 10^9 cps. In the practical sense much of these potential stimuli arise from power lines and power devices of one sort or another. Sensitive magnetometers with a least count of 1 γ and a frequency response of about 500 cps are available presently for less than $4,000. Sensitivity requirements greater than 1 γ are met by the use of highly specialized instruments for which we have no cost estimates at the moment. Typical of such devices are the highly sensitive optical pumping magnetometers as the rubidium vapor and metastable helium devices. These units are portable, small in size and free from vibration effects. They have ultimate sensitivities of about 0.001 γ and have demonstrated sensitivities of 0.01 γ in use.

3.8.3 CONTROLLING THE MAGNETIC FIELD

Through the use of such apparatus as Rubens' Coils, Helmholtz coils and other arrangements of the same genre (these will be discussed in subsequent sections of this part of our report) coupled with sensitive tri-orthogonal field sensors and a dynamic driving current system, one may substantially reduce the earth's field to "zero" within a limited physical volume. It is, however, essential to recall at this point that man-made field disturbances normally occur at relatively high frequencies. To date, no dynamic approach we have been able to uncover (or invent) is able to cope with the problem of producing "zero" field levels in a working volume of useful size. This statement is of particular significance for the researcher who is not able to withdraw to a locale distant from equipment and machinery producing artificial magnetic fields. It is pertinent to observe that we would be satisfied—at least initially—with a definition permitting "zero" to equal $<10\ \gamma$. It is also apropos to mention that as these coil arrangements and their control systems are pushed into higher frequency mulling requirements their cost can be expected to rise exponentially. If then, in addition to providing the solution to a difficult nulling specification, we further may require that the coil complex be capable of re-inserting a precise dynamic experimental field, the situation becomes virtually untenable.

It is for these reasons that we have taken the approach favoring a nulling system requiring no sensors, no control system, and no power. The philosophy involved is straightforward: If one can design magnetic shields on a predictable basis and at a supportable procurement cost, one should be able to produce experimental working volumes of substantial size which are essentially field-free; once these are in hand, one may then insert static or dynamic fields on an easily controllable and accurate basis with a suitable coil system internal to the shield structure. Such an arrangement makes possible full control of the magnetic stimuli to which the bioentity is then subject.

A reasonable literature exists on the theory and design of magnetic shields. A number of industrial organizations produce magnetic materials which are applicable,and several will design shields to order. It was a matter of some concern to discover that a number of organizations designing and supplying fabricated magnetic shielding structures possessed no arrangement or instrumentation adequate to evaluate the structures they built. This fact notwithstanding, we are most appreciative of the selfless and cooperative responses we experienced with all segments of industry contacted to date.

Our study of past work in the establishment of the theory of shields and their design followed parochial paths.

A. P. Wills (3- 61) in the 19th century published an analysis of the shielding problem in response to the then recognized problem of shielding delicate magnetic suspension instruments against earth currents produced by trolley systems. His work represents an extension of approaches to the problem made earlier by Rucker in 1894, duBois in 1898, and duBois and Rubens in 1898. His analysis is extremely useful, but leads to fairly complicated calculations. He shows quite conclusively that the shielding attenuation obtained with a multiplicity of relatively thin concentric shields is far greater than that possible with a single shield equal in thickness to the complete set of concentric ones (including the interposed air spaces). Wills has considered only the initial permeability of the magnetic shielding materials and the same permeability throughout the shield system. He further made no observations concerning the fact that shield internal flux densities are maximized at shield sections parallel to the field axis, but farthest from that axis. These latter points are matters of concern. His results were limited to triple shields.

T. E. Sterne (3- 62) of the Harvard College Observatory addressed himself to the problem of evolving a practical formulation applicable to coaxial cylindrical shielding structures consisting of n-shields of any radial dimensions, in contact or separated by gaps and composed of the same or different materials. His formulation of the problem is, as he states, similar to that of Wilson and Nicholson (3- 63) except for its application to cylinders rather than to spherical shells. Sterne properly points out that the analytic formulation is exact and that no assumptions are required—other than that the cylinders involved must be assumed to be either infinite in length or to have closed ends. His analysis results in an easy-to-handle set of recurrence formulas. However, he does not consider the variation in flux density in the shielding structures which was mentioned earlier. This variation can be taken into account to some extent by the appropriate modification of the permeability value for each shield based on step-wise computation of the shield attenuation rather than on the direct recursive calculation he outlines. It should be noted in passing, that at least one manufacturer of a high-quality shielding metal, raised serious practical questions concerning Sterne's experimental test of his formulation.

In 1956, Wadey (3- 64) evolved a recursion formula suitable for automatic computation. The most important contributions in his paper, however, relate to his careful discernment of the practical aspects of the problems involved. For example, it is recognized that the useful effective thickness of a magnetic shield shell is governed by the expansion (after Rücker)

$$t \leq \frac{3a_1}{2\mu} \qquad \text{where } t = \text{thickness}$$

a_1 = inner radius of the shell

μ = permeability of the shell material

In other words, no significant improvement in field attenuation will be attained if the thickness exceeds $\frac{3a_1}{2\mu}$ in value.

He further shows by example that while the use of a geometric series for devising the successive values of shell radii (Rucker) improves the shielding factor as originally formulated, the use of modern, high permeability metals makes the necessity for such a design constraint very much less significant. Wadey recognized clearly that in the practical case, one was not dealing with either infinite cylinders, nor very often with cylinders closed at both ends. To this point he observed the well-known difficulty of attempting a mathematical solution to the end-effects and relates the results of measurements made by Esmarch (3- 65). Esmarch plotted, from experimental measurement, shielding ratios as a function of distance from the open end of the shield along the axis of the shields. Wadey also treats the computation of shielding ratios as a function of frequency (after S. A. Shelkuneff, BSTJ, 13:532, 1934). Another matter of practical consequence Wadey has noted is the fact that proportional increases or reductions in shield sizes produce essentially the same attenuation results. This is based on the observation that the shielding ratio depends primarily on the value of permeability (μ) and the ratios of the shield dimensions.

It is sufficiently clear that metal shield thickness may be small indeed. However, severe practical problems limit the minimum thickness. These problems relate first to the fact that in order to obtain the excellent characteristics in permeability, etc. which modern materials have, the metal must be free of all stress, both magnetic and mechanical. Stress-relief is obtained by a very high temperature (>2000°F) annealing process in a dry hydrogen atmosphere. Generally speaking, structures undergoing such annealing processes must be self-supporting. Large structures fabricated from extremely thin materials will not withstand the process.

In 1954, Teasdale (3- 66) wrote a practical paper on magnetic shields. He shows that the ultimate limit of achievable shielding for single shields is

$$\frac{(\mu + 1)^2}{4\mu} \approx .25\mu \text{ for cylindrical shields}$$

and $$\frac{(\mu + 2)(2\mu + 1)}{9\mu} \approx .222\mu \text{ for spherical shields}$$

He presents in graph form, data indicating the relative merits of various magnetic alloys as a function of the ratio of metal thickness to outer radius. Of greatest interest perhaps are his experimental results showing shield attenuation along the axis of the shield and at its open ends.

Wadey (ibid) realized that previous treatments of magnetic shields assumed <u>constant</u> values for the permeabilities of the magnetic materials used. Therefore in 1957 he reviewed his previous work and wrote the extremely useful paper referenced here (3-67).

The direct use of formulation as developed by Sterne (ibid) and others leads to computed values of shield attenuations which may be far in excess of what is actually realized. It is further the case that unless a systematic and supportable approach is used in the determination of the proper value of material permeability for each shield of a nest, additional errors of consequence creep into the computed value of attenuation.

It is clear that from the analysis (3- 68) of the flux density, for both a sphere and an infinitely long rod lying in an infinite homogeneous field, that for the former, the internal field is $H_i = \frac{3H_o}{\mu + 2}$ where H_o = external field, and the induction inside is $B_i = \frac{3\mu B_o}{\mu + 2}$. For large values of permeability, these expressions reduce to $H_i = \frac{3H_o}{\mu}$ and $B_i = 3B_o$. In the case of a solid infinite cylinder with its axis perpendicular to the field, relationships are $H_i = \frac{2H_o}{\mu}$ and $B_i = \mu H_i = 2\mu_o H_o$, ($\mu_o = 1$). The latter case is, of course, closely similar to the circumstance wherein we are dealing with a shield shell— except that it is not infinite in length and except that it is hollow.

As Wadey Points out, for a shell with a reasonable value of μ (permeability) practically all the flux is carried in the shell and a weak uniform flux is carried in the airspace within the shell. We know that the flux density (B) within a solid permeable cylinder is equal to $2B_o$; what is the situation in a shell wherein the density of flux is not necessarily uniform? And one must simultaneously recognize that as a consequence neither will the value of effective permeability for the material be constant.

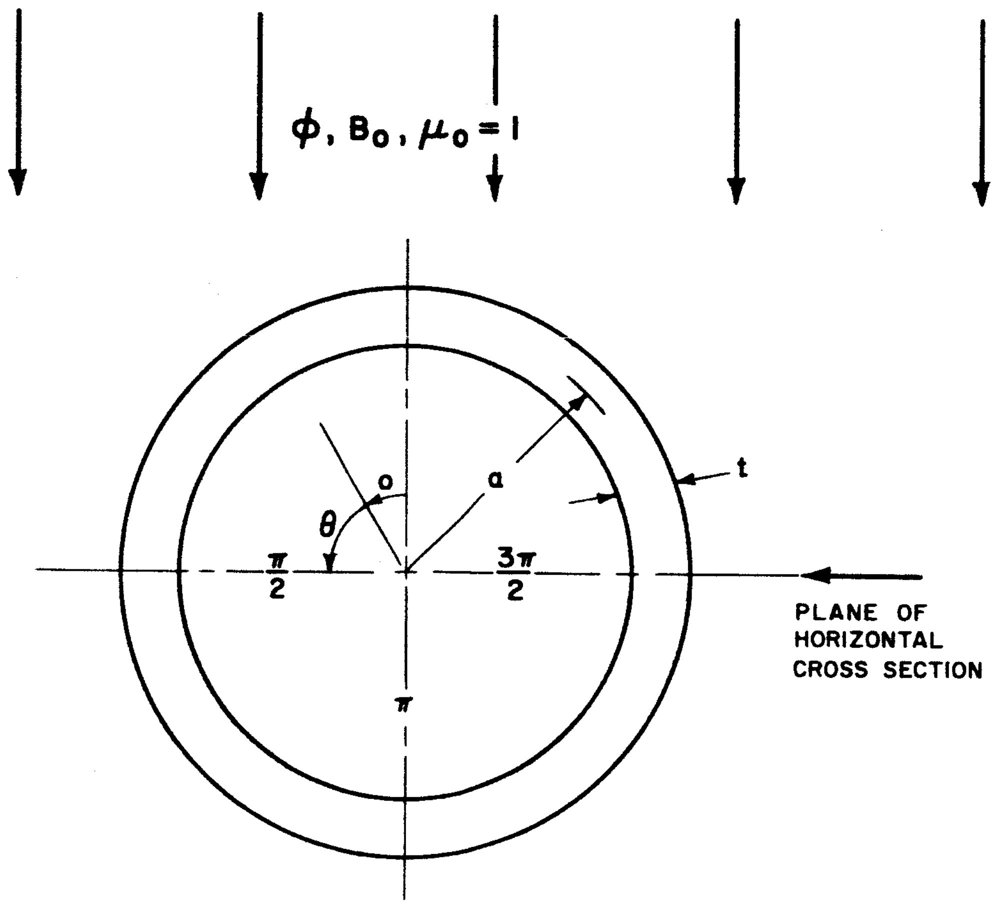
Based on Wadey's explanation of the matter, see Figure 3.8-4, the total flux density at any point may be expressed as:

$$B(\theta) = 2B_o[1 + \frac{a}{t} \sin\theta]$$

t = shell thickness

a = radius of shell

and most important, it follows that at $\theta = \frac{\pi}{2}$ (the horizontal cross section), the flux is concentrated by a factor $\frac{a}{t}$ over that which one would obtain for a solid cylinder. This concentration factor is, in practical cases, a substantially large number, and it is apparent that we must take care to avoid saturation of the shield shells—this being particularly true in the outer shells. A second observation of almost equal importance is that since the permeability is a function of flux density, it also will vary around the shell. In the face of this variable situation and



$$d\phi = 2B_0 \ell a \, d\theta \cos\theta$$

where ℓ = LENGTH OF SHELL

a = MEAN RADIUS OF SHELL

$$\phi(\theta) = \int_0^\theta d\phi$$

$$= 2B_0 \ell a \sin\theta$$

AND $B(\theta) = 2B_0 + \dfrac{\phi(\theta)}{\ell t}$; $B = 2B_0$ BY CONTINUITY

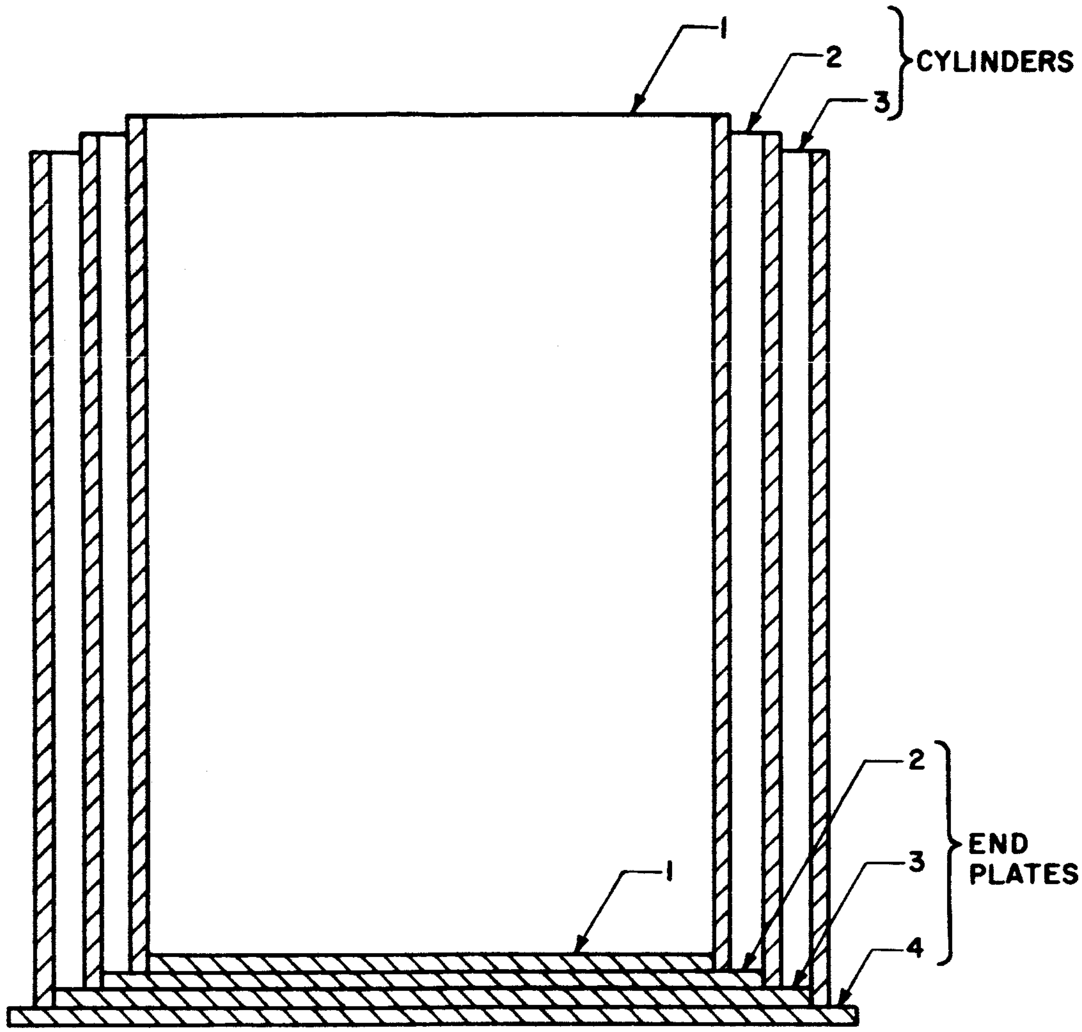
$$= 2B_0 \left[1 + \left(\frac{a}{t}\right)\sin\theta\right]$$

Figure 3.8-4 Wadey's Figure Defining Flux Concentration in lieu of a rigorous, analytic solution for the physical situation presented, Wadey suggests the use of

$$B_{eff} = 0.6 \left(\frac{a}{t}\right) 2B_o$$

and $\mu_{eff} = \mu$ (corresponding to the flux density B_{eff})

We are presently using this suggestion, but intend later to attempt its modification based on careful experimental measurement. Based on analog studies on current-field distributions made in these Laboratories, it was our conviction that many presently-designed magnetic shields were over-engineered, resulting in substantially increased fabrication costs. Based on our experience and the stated assumption, we designed the nest of shields illustrated in Figure 3.8-5. Such a nest of shields costs about $50 in small quantities and for static earth fields shows an attenuation considerably in excess of 5000. A more accurate statement on the static field attenuation will be forthcoming in later reports after additional measurement effort is completed. At that time we expect to be in a position to establish a more practical relationship between measured and computed attenuation factors for multiple shields as well as useful curves relating shield end effects to dimensional and other nest parameters. The results of our present limited effort here are already quite useful. Figure 3.8-6 shows representative shielding attenuation for the illustrated nest over the frequency range of 100 to 10,000 cps, and Figure 3.8-7 illustrates the calculated effect



CYLINDERS
1. 6.0" ID x 9.0" LONG
2. 7.0" ID x 9.0" LONG
3. 8.0" ID x 9.0" LONG

CYLINDER WALL IS OVERLAPPED $\frac{1}{2}$" AND SPOT WELDED EVERY $\frac{3}{4}$"

DIAMETER TOLERANCE IS $^{+0625}_{-000}$ INCHES

END PLATES
1. 6.0" DIAM
2. 7.0" DIAM
3. 8.0" DIAM
4. 9.0" DIAM

DIAMETER TOLERANCE IS $^{+000}_{-0312}$ INCHES; PLATES TO BE REASONABLY FLAT

MATERIAL: 0.020" (NOMINAL) MU-METAL

ALL PARTS TO BE DRY HYDROGEN ANNEALED

Figure 3.8-5 Shield Nest

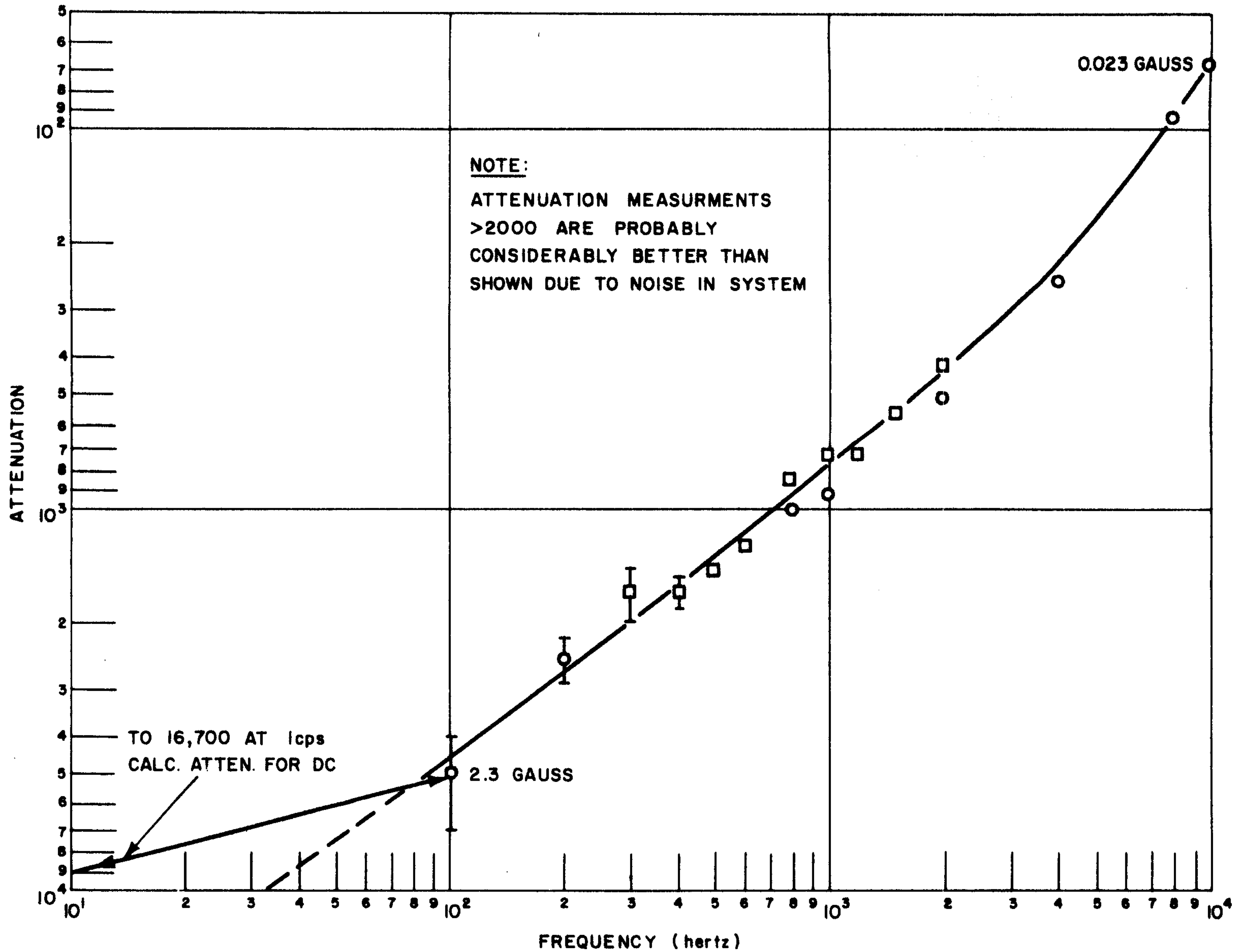


Figure 3.8-6 Attenuation Vs. Frequency

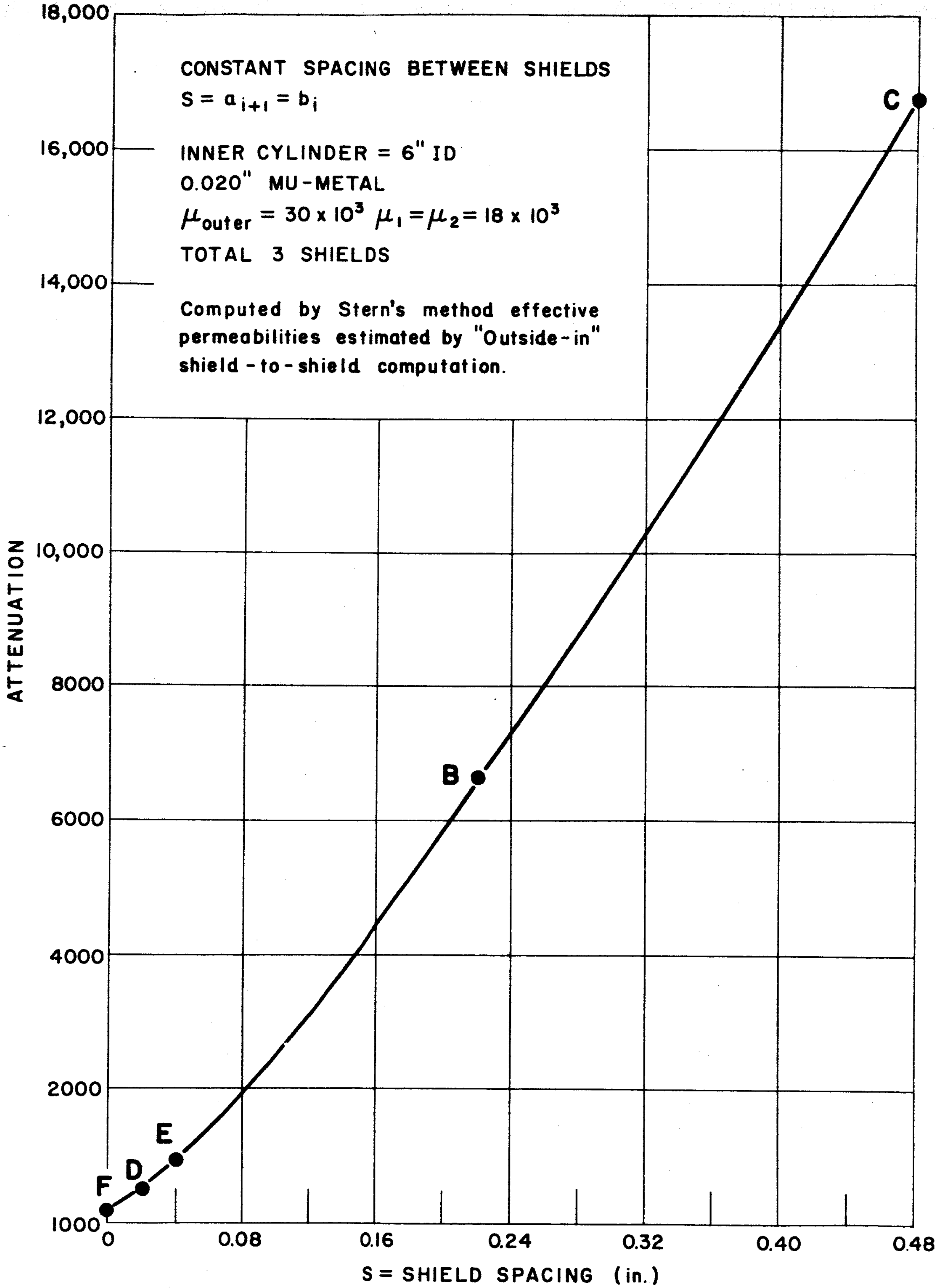


Figure 3.8-7 Spacing Vs. Attenuation

on attenuation of variation in shield-to-shield spacing, based on referenced shield sets. The calculated attenuation for the specific shield nest illustrated in Figure 3.8-5 (static field) was 8900 at 120 cps. This would indicate an internal field of about 5.67γ, assuming an ambient level of 50,000 γ. Rough measurements using a 2.3 gauss external 100 cps field showed an attenuation factor in excess of 5000 and thus an internal field of about 47 γ. Our present instrumentation does not permit us to measure, with any reasonable accuracy, attenuations in excess of 5000 below 100 cps. Within a few months, we expect to be prepared to make measurements of field to 1 γ over the frequency range of dc to 500 cps. Detailed data on shield designs are also expected to be made available at that time. However, we are pleased with the good performance, ease of approximate design and low cost of our initial approach to magnetic shield effort. Later work is expected to relate to the design, fabrication and measurement of shield nests of reasonably large diameter.

Computation data for the attenuation of the shield nest illustrated in Figure 3.8-5 follows:

Magnetic Shield Computation Results

The estimated values for the permeability (μ) of each shield were obtained by gross approximation of shield induction from the outside-in, in a stepwise manner.

Thus for the outer shield, assuming $\mu_o H_o = 0.5$ gauss

$$B_3 = 0.6\frac{a}{t}(2)(.5)$$

where $\frac{a}{t} = 200$

then from the B-H curve for mumetal

$$\mu_3 \cong 48 \times 10^3 \text{ (dc)}$$

$$\mu_3 \cong 28 \times 10^3 \text{ (60 cps)}$$

$$\mu_3 \cong 22 \times 10^3 \text{ (120 cps)}$$

The procedure is continued for the second and third shields of the nest and

$$\mu_2 = \mu_1 = 20 \times 10^3 \text{ (dc)}$$

$$\mu_2 = \mu_1 = 18 \times 10^3 \text{ (60 cps)}$$

$$\mu_2 = \mu_1 = 15 \times 10^3 \text{ (120 cps)}$$

Sterne's method (ibid) is then applied, based on the following formulation:

$$\epsilon_i = [(b_i - a_i)/b_i] - \tfrac{1}{2}[(b_i - a_i)/b_i]^2$$

$$\epsilon_i, i + 1 = [(a_{i+1} - b_i)/a_{i+1}] - \tfrac{1}{2}[(a_{i+1} - b_i)/a_{i+1}]^2$$

$$\mu_{i+1} = \alpha_i u_i + \beta_i v_i; \quad v_{i+1} = \;_i u_i + \delta_i v_i$$

where $\alpha_i = 1 - \epsilon_i, - \epsilon_{i,\, i+1} + (\mu_i + 1)\, \epsilon_i \epsilon_{i,\, i+1}$

$$\beta_i = \epsilon_{i,\, i+1} (1 - \epsilon_i) + (\epsilon_i/\mu_i)(1 - \epsilon_{i,\, +1})$$

$$\gamma_i = \mu_i \epsilon_i + \epsilon_{i,\ i+1} - (\mu_i + 1)\ \epsilon_{i,\ i+1}$$

$$\delta_i = 1 - \epsilon_i - \epsilon_{i+1} + \epsilon_i \epsilon_{i+1} [(\mu_i + 1)/\mu_i]$$

and $\mu_i = v_i = 1$

and shielding factor $F = \frac{1}{2} (u_{n+1} + v_{n+1})$

RESULTS OF COMPUTATION

n	ϵ_n	$\epsilon_{n-i,n}$	α_n dc	60	120	β_n	n dc	60	120
1	.0066	-	17.67	15.97	13.47	.127	115.3	103.9	86.53
2	.0057	.128	13.68	12.4	10.48	.112	100.1	90.11	75.11
3	.005	.113	.995	.995	.995	.0	240	140	110.
4	-	-	-	-	-	-	-	-	-

n	δ_n	u_n dc	60	120	v_n dc	60	120
1	.865	1	1	1	1	1	1
2	.882	17.8	16.1	13.6	116.2	104.8	87.4
3	.995	257	212	152	1882	1542	1097
4	-	256	211	151	63475	31235	17790

$F_{dc} = 31865$

$\therefore$ 1.6γ for an external field of 50,000

F_{60} cps = 15,723

$\therefore$ 3.2γ for an external field of 50,000

F_{120} cps = 8970

$\therefore$ 5.6γ for an external field of 50,000 γ

Our studies of systems for the generation of dynamic homogeneous, magnetic fields has not yet been as deep as that related to magnetic shields. However, the key approaches to such field generation relate to methodology described by Rubens (3-69), Dwight (3-70), Dwight and Peters (3-71), Grant and Strandberg (3-72), Wolff (3-73) and Lock (3-74).

When one uses two circular flat coils of radius r separated by one radius, the configuration is called a Helmholtz Coil. The field at the center of the configuration is

$$H \; .8992 \frac{NI}{R} \text{ oersteds (See Figure 3.8-8a)}$$

where I = amperes

N = turns on each coil

R = radius in cm.

The field is uniform within .02% for a sphere of radius 0.1R and 0.2% for a sphere of radius .2R. For Rubens coils, five square coils are employed per axis:

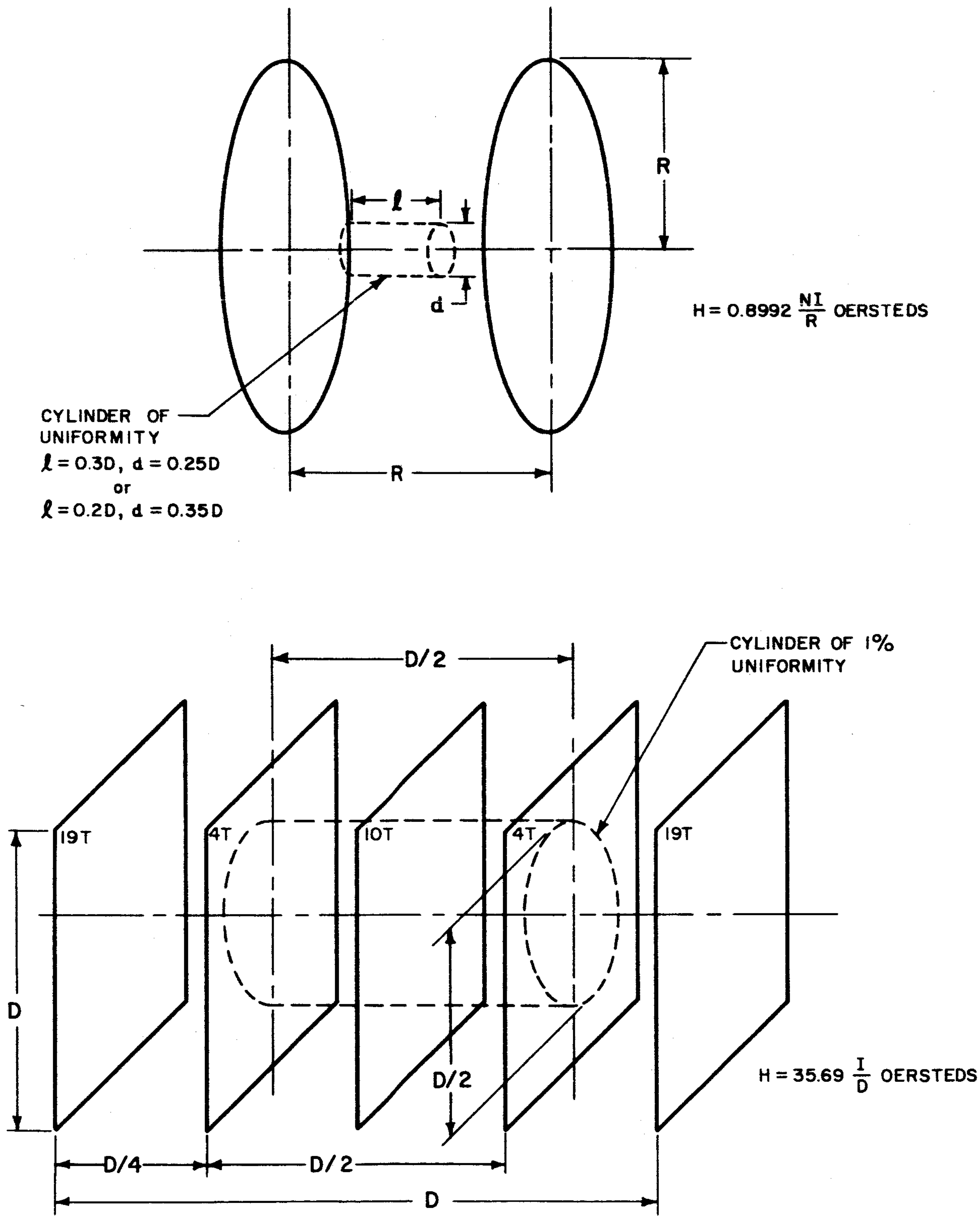


Figure 3.8-8 Helmholtz and Ruben's Coils

$$H = 35.69 \frac{I}{D} n \text{ oersteds (See Figure 3.8-8b)}$$

where I = amperes

D = length of a coil side in cm

N = number of multiples of turn sets

The windings on each coil of a Rubens coil have a specific ratio. It has been demonstrated that the opening available for access to the center of a three-axis Rubens coil arrangement is about a fourth of that available in a similar Helmholtz coil. For the Rubens coil, the field uniformity is 1% within a cylinder $\frac{D}{2}$ in length and $\frac{D}{2}$ in diameter.

In the circumstance where Helmholtz or Rubens coils are used to attempt to null the ambient field—and then simultaneously to reintroduce a desired dynamic field, the system sensing magnetometer must have programmed superimposed inputs to accomplish the desired end result.

For the situation we envision for a typical MET, the experiment environment will first be nulled to "zero" by a suitable shield nest and then have introduced the desired dynamic field as generated either by Rubens or Helmholtz coils. In any case, careful empirical design and study will be involved.

The matters of fundamental importance in all the foregoing discussion relate to several facts. First, it is clearly possible to reduce the magnetic field of the MET volume to a pre-determined level and at a cost which is not ridiculously high. Second, it is possible to introduce desired fields for the MET through the use of Rubens, Helmholtz, or similar arrangements. These new fields may be static or dynamic, or a combination of both.

We are keenly aware of the necessity to monitor the magnetic fields in the MET. This problem is, however, second (by far) in difficulty to that of monitoring the bioentity under study. This comment is pertinent because all the foregoing discussion assumed the introduction of no influences able to disturb the bases of shield and/or coil analysis. While the problems associated with the observation of the bioentity in the MET will be discussed in somewhat greater detail elsewhere in this report, it is apropos to comment briefly on the effects of some typical and presently routine measurement methods.

Let us assume that the bioentity is a hamster with an implanted squegging telemeter. The telemeter coil has (say) 100 turns of wire which carries a peak current of 4×10^{-3} amperes. The coil diameter is 2 cm. At the center of such a coil the magnetic induction (peak) is approximately:

$$B = \frac{\mu_o 2\pi NI}{10r}$$

$$= \frac{16.28 \times 10^2 \times 4 \times 10^{-3}}{10}$$

$$= \frac{25.12 \times 10^{-1}}{10}$$

$$= \underline{25{,}120\gamma} \text{ peak value}$$

Where $\mu_o = 1$

$r = cm$

$N = turns$

$I =$ current (amps)

Now let us assume that a photic stimulus is introduced to the experimental volume. The lamp might be a flashlight bulb driven by (say) 3.0 volts and requiring 50×10^{-3} amperes of current. Then the magnetic induction at a radial distance of one centimeter of one of the two lamp lead wires may be computed approximately as:

$$B = \frac{\mu_o 2I}{10r}$$

$$= \frac{2 \times 50 \times 10^{-3}}{10}$$

$$= \underline{10{,}000\,\gamma}$$

Where

$\mu_o = 1$

I = current (amps)

r = radial distance in cm

We know, of course, that careful attention to conductor shielding, severe limiting of conductor current, etc. will all contribute to a sharp reduction in the introduction of unwanted perturbations in the experimental volume energy continuum. The examples given above are not to be taken as representative of the problem we expect to have, but rather as an <u>understatement</u> of the problems <u>presently existing</u>

(although perhaps undesirable) in many biological experiments. In any case, the examples given only emphasize the fundamental requisite for the instrumented biological experiment: the experiment should be directed to the desired hypothesis test based on a practical design distilled from cooperative effort, study and contribution by the several disciplines actually involved.

3.9 DISCUSSION OF ATMOSPHERIC ELECTRICITY

In an oversimplified picture the earth and its atmosphere form a leaky capacitor. One electrode is the earth's surface, the other the ionosphere. This capacitor is maintained at an average potential of 300 kilovolts by the action of thunderstorms, while experiencing an average discharge current of 1400 amperes. Our main interest lies in the region near the earth's surface. Here the average potential gradient is about 100 to 150 volts/meter, the yearly means remaining quite constant (3-75, 3-76). At Memambetsu (3-77) for the years 1950 through 1956 the yearly means were 122, 129, 130, 124, 121, 101, 111 volts/meter for undisturbed days at a single location. Solar flares, thunderstorms, aurora etc. (3-78, 3-79) will create local as well as widespread disturbances increasing or decreasing by orders of magnitude these values. The earth's surface is negative with electron (and negative ion) flow upwards from the surface. Ample conductivity from electrons and negative ions is produced in the lowest meter of the atmosphere by the combined ionizing radiations coming from radioactive rocks, radioactive gases and cosmic rays. These produce, on the average, 10 to 50 ion pairs/cm^3/sec. It has been suggested that 1944, the year before the Hiroshima atomic blast, should be considered as the last base year for a long time to come. While the conductivity is ample to maintain approximately the 1400 to 1800 amperes over the whole surface of the earth, this amounts to only 0.3×10^{-12} amperes per square foot. It is the present hypothesis that this leakage current is replenished by both point (corona) and lightning flash discharge from thunderstorm activity directly beneath the thunderclouds. The current is thus reversed, electrons flow toward the earth, and locally the atmospheric potential is reversed. Under a local thunderstorm this current may average about 0.3 to 1.0 amperes. The currents and potentials vary yearly, seasonally, monthly diurnally and hourly. Flora and fauna on the surface of the earth are continually subjected to both changing potential from the ground surface upwards, as well as currents in the ground itself. These ground currents, or Telluric currents essentially carry away from the thunderstorm areas the current supplied by the thunderstorm and supply the currents for the fair weather areas. Ground potential gradients, as a result of these currents, are very small and on the order of 1 millivolt per kilometer. Some of the telluric currents are induced by the motion of water through the geomagnetic field, a fraction is produced electrochemically and locally a fraction is man made; the major portion is due to currents in or above the ionosphere (3-80, 3-81). Here we are not considering the huge postulated currents in the earth's core producing the geomagnetic field. These conjectural currents are confined to the electrically conducting earth's core. Recent sensitive measurements of the micropulsations of the earth's magnetic field and the telluric currents show a close correlation however (3-82). These have also been correlated with injections into the upper atmosphere of plasma from solar plasma pulsations as well as thunderstorm activity hundreds of kilometers from the site of measurement.

That the electrostatic field has a biological effect directly or indirectly has been shown by many workers (3-2, 3-32, 3-83, 3-84, 3-85, 3-86). Directly such effects may be sensed through specific receptors or at the cellular level, or indirectly by changes in the temperature, humidity, light level or even long term effects on the food and water supplies to the organism (3-87, 3-88, 3-89, 3-90).

In the use of a Managed Energy Terrella where electrostatic fields and earth currents are eliminated, we are depriving the bioentity of a natural environmental variable perhaps useful or necessary to its organization. The facility for inserting such fields should then be an integral part of an MET not only to perform an experiment with such fields, but to be able to provide a "normal" environment for the specimen when conducting an experiment with other parameters. Sollberger, in discussing the basal state remarks: "The basal condition problem actually reminds one of the experiments with constant conditions in rhythm research. This state is certainly <u>not</u> <u>normal</u> and may interfere with the equilibrium of the living system." (3-2)

As a side issue to the problem of the effect of electrostatic fields, is the problem of the effect of gaseous ions on both plants and animals. While this question is still up in the air (no pun intended) there is a considerable evidence for both pro and con (3-91). The major problem in the field is proper instrumentation and the control of extraneous variables. Frey seems to have made good progress in instrumentation improvement. He feels that the hypothesis that negative ions have a reserpine type bio-behavioral effect can be made. Care should be taken then, in any experiment where this effect might be of significance, to monitor the ion content of the air. Many simple mechanisms besides those previously mentioned can cause ionization of the air. Low humidity air moving rapidly over plastic filters in, for example, an air conditioner or ventilator can strongly change the ion content of the air. The use of x-ray or ultraviolet wavelengths can directly cause massive air ionization with the resulting ambiguity as to the direct cause of observed effects.

At the present time it is almost a universal practice to take no cognizance of the ion content of the air in biological experiments which are concerned with other variables.

3.10 DISCUSSION OF INFORMATION CLASSIFICATION

In the course of our studies of the MET it became apparent that there was an urgent need for storage and retrieval of the many references derived from many disciplines which were necessary and were accumulating rapidly. The disciplines covered were in general the Life Sciences and the Physical Sciences but also included the philosophy of science, mathematics, logic, statistics, computer technology, and theory of experiment design. Last but not least, references of the subject of information storage and retrieval were also to be included; this class then included itself.

One of the difficulties encountered in developing such an index, in our case, was that while subject indexing of disciplines could be used, the areas which overlapped were large and would become very troublesome. The whole category of Life Sciences Instrumentation was an interface area of sufficient magnitude to merit a classification of its own. If one was generous in his definition of the Life Sciences, however, this area would encompass nearly all of the material in the index. Subject indexing in the usual sense was not considered useful.

Another commonly used technique of classification is that of heirarchial indexing with major subject indexing. This system can lead to such difficulties as the following: Four instruments, all with the same end purpose of measuring GSR may become widely separated in the index because the first may use tube circuitry, the second solid state electronics, the third information transmission by telemetry and the fourth digital readout. Only by extensive searching with the aid of full cross indexing and "see also's" could these four references be found.

Alphabetical indexing by subject again allows material which should be grouped together to become separated. In addition, it becomes increasingly difficult for the indexer to choose the "correct" single word to use to index by. If several words are chosen, cross indexing then becomes a large part of the index with multiple entries. Alphabetical indexing becomes a problem both for the indexer and the retriever.

It was planned that entries into our system would be made by the engineers and scientists who would be using the system. Whatever system was to be used it would have to be easy to make an input and to perform the output operation. Since many individuals were expected to use the system and since the inputs of one would be useful outputs to another, a fairly simple system had to be considered. Research workers are notorious in their lack of enthusiasm for a system which is difficult to use.

With these various constraints, difficulties and drawbacks in mind, an investigation of a relatively new method of information classification was begun. This system is termed "Coordinate Indexing."

In the early 1950's a technique was developed for indexing which utilized the logical operation of the intersection on coordination of descriptive terms, utilizing the "and" function of Boolean algebra (3-92). This system proposed that particular items of information be found by combining items in different categories or alternatively by the intersection of general categories. This is in vivid contrast to conventional systems of indexing.

As a simple example, let us consider a two-dimensional grid or cartesian coordinate system. Assign to each integer on the x and y axes a "term" such as: x axis 1 = amplitude, 2 = frequency, 3 = phase, 4 = pulse, etc.; y axis 1 = modulation, 2 = detection, 3 = conversion, 4 = amplification, 5 = generation, etc. Then for each point in the plane described by a pair of integers we have the intersection of two ideas. For example, x = 3, y = 2 is the combined idea of phase detection; for x = 2, y = 1 we have frequency modulation etc. This simple idea can be extended without difficulty to 3, 4 or n dimensions giving us an extremely powerful tool with which we can index without limit any combination of ideas (or documents containing these ideas). Retrieval of the information is no more difficult than indexing and has some benefits not at first apparent. For example, every article containing the word "temperature" (as its describing term) would be retrieved if only that word were used in a search of the index. On the other hand, probably only one article or document would be retrieved if the combination of the terms: analog, computer, simulation, man, circuits, was used to search for an article. The document, "Analog Computer Simulation of Temperature Regulation in Man" was indexed by these five terms (and a few others) in our document collection.

As can be seen from this brief description, this simple idea is a very powerful one. It had many properties which made it suitable for our purposes. It remained to implement this system by adapting it to our use. One major advantage of the system which we felt to be particularly useful was that it will often disclose to the searcher (especially as the system gets larger) more than had been put into the system. This sounds like one gets something for nothing, which is not true, but by combining terms we may get information which although implicit in the system was never explicitly recognized. Thus, in effect, the system is performing an operation which until now has been considered to be in the exclusive province of the mind. One major disadvantage of the system is that in its most primitive form no provision is made for "browsing," and even with aids for "browsing" this pleasure is not as easy to obtain as in other indexing systems.

In putting a coordinated indexing system into use in our laboratory several decisions on the mechanics of the system had to be made. Two of the most important were: one, should a mechanical search system be used, and two, how were the descriptor words or uniterms to be selected. After some investigation it was decided that a mechanical system of searching was to be avoided. In a system with fewer than 5,000 documents, a mechanical system (key-sort, peek-a-boo, magnetic tape, etc.) only leads to delays in indexing and searching, frustration when it breaks down, errors, hangups, wasted time, higher cost and many other disadvantages with little to offer except novelty and glamour. A hand posting on and hand searching of 3 x 5 cards is fast, simple and inexpensive. A simple technique of "terminal digit posting" allows fast comparison and intersection of the uniterms. This was adopted. In regard to the development of a list of coordinate terms or uniterms it was decided that in our particular case a preselected list of terms would be out of the question because of the enormous range of subject matter to be used in the system and because of the time required to develop such a list. Further, a list developed by one worker might not use the same terms that would be natural to another worker. Such an a priori list was ruled out. It was felt that the list could be generated as the file was developed, and the list would grow as the file grew. As far as we know, there is very little experience with a uniterm system developed along these lines. Certain difficulties were expected and the users were forewarned. Other difficulties, such as the propensity of one researcher to use hyphenated terms rather than single words as descriptors, were overlooked, but caught in time. Single words (uniterms), two or more precoordinated words (3-93), or even phrases can be used as the descriptors in a coordinated index. It was decided (and now firmly enforced) that this system was to use only a single word as a descriptor. A few (and a very few) special terms were allowed which did not meet this criterion, such as AC, DC, FM, AM. As the number of descriptors grew an alphabetical list was edited and distributed to the users of the system. Editing of such words as calculation, calculating, calculated, calculate to the single term calculation was done. This reduced the number of uniterm cards in this case by 75% without loss of meaning or change in the concept. The system users are then urged to use this preferred list.

In initiating this system the enclosed directions were distributed to prospective users (two engineers, one physicist, one biologist and one secretary). Very few questions had to be answered by the author and the system got under way in a few days. A large number of entries were made in the first few weeks tapering off to about two or three per week per user. The system now has approximately 180 uniterm cards. A simple subject index with no cross indexing would have required at least one card per reference. With cross indexing equivalent to that obtained by coordinate indexing approximately four or five times that number of subject cards would have been required since approximately four or five uniterms are used to describe each document or reference. Practically, it is expected that the number of documents may grow by a factor of 10, with the number of uniterm cards increasing by less than a factor of two. Theoretically, 180 uniterms taken even five at a time would give ${}_{180}C_5$ combinations, or unique five-word descriptions. Thus 180 uniterms could uniquely describe ${}_{180}C_5 = \frac{180!}{(180-5)!\ 5!}$ 1.5×10^9 documents if all the combinations were meaningful. As of the present writing, there are no serious complaints against the system, and it is expected to be useful for years to come in this Life Sciences Instrumentation Laboratory.

An excellent general source of information on coordinate indexing is "The State of the Art of Coordinate Indexing" (3-94). The emphasis in general in coordinate indexing at present is, however, on automation or mechanical means of search with little or no help for the small collection. It is hoped the system developed on this project will be useful for those requiring a small (say up to 5,000 references) simple, inexpensive, but useful system incorporating the benefits of coordinate indexing.

COORDINATE INDEX SYSTEM FOR REFERENCES

DIRECTIONS FOR SETTING UP AND USE OF UNITERM INDEX

It has become apparent that a filing system be set up for the large number of references already acquired and expected to be accumulated on Project 15G-B2299. There are several requirements for such a system.

1. That documents will be easily filed and more easily retrieved
2. That documents can be found by many routes or independent paths of search
3. That the system be simple so that it will be used and is not easily gotten out of working condition
4. That it can be expanded to any number of documents but will be useful for any size

Any such system should have these four basic operations.

1. Initial entry of document into system
2. Retrieval of data from system
3. Return of data to system
4. Destroying of obsolete data

One such system which seems to fill all of the above requirements is the Uniterm or Descriptor System, or at least a modification of it. This system would consist of three elements.

1. A retrieval file (3 x 5)
2. A document card collection
3. A document collection

Uniterms or descriptors are single words, generally nouns, which contain the essence of the material in a reference. Several of these words are used to describe the document. Probably not less than two or more than fifteen are used, but on the average four or five are used. All of these terms are used in the initial listing of the document; one or all may be used to retrieve the document.

Retrieval File (3 x 5) (Uniterm Card File)

The retrieval file has a card for each Uniterm. On the Uniterm card is listed each document which uses this word to describe it. The unique acquisition numbers of this card are hand posted by the secretary in charge of the file. These cards are filed strictly alphabetically. (See sample card)

Document Card (5 x 8)

The document card collection is essentially the primary document collection. Each card in this collection has a unique acquisition number, a complete citation in uniform format (see reference format), a list of descriptors for filing a more complete list of key words, comment on content or value of reference and commentor's initials. The acquisition number is assigned to the document card in numerical sequence by the secretary in charge.

Document Collection (3 ring $8\frac{1}{2}$ x 11 loose leaf binder)

Each reference document which is readily accessible in copy will be given the same acquisition number as the document card describing it. Each researcher will, when obtaining a copy of a document for himself, obtain a second copy for the document collection. These documents will be filed in loose leaf notebooks by numerical order only, by the secretary in charge and removed only by the secretary in charge. This will comprise the secondary document collection. For those documents which are not readily accessible in copy or which are too bulky (books) or expensive to copy a single sheet with the accession number and location of the document will be inserted in the document file. For extended personal use the secretary will order Xerox copies for you.

The operation of this system will proceed as follows. As each pertinent document is found, the researcher will fill out by hand a preliminary document card. This card will conform to the format shown on sample document card and reference format sheet. These cards may be revised and updated, or continuation cards may be used if necessary and at any time. Indicate to secretary that a card is an addition, correction or continuation. All cards will be typed on one side only. The secretary in charge will type this card in the preferred format and assign the acquisition number (in strict numerical sequence). These cards are filed in strict numerical sequence. She will then post by hand the acquisition number on each Uniterm file card indicated. These cards are filed strictly alphabetically. If the document has been obtained in copy, this is also given to the secretary. If not, the secretary will obtain one copy for the researcher and one copy for the document file.

To retrieve material from this file it is only necessary to decide what words (Uniterms) are desired, look these up in the 3 x 5 Uniterm file, ascertain the acquisition numbers and find these numbers in the document card file. Comparison can be made between any two or more Uniterm cards to find those documents which are pertinent to the combination of Uniterms chosen.

Note: A peculiar feature of this system which will be used is "terminal digit listing." This is merely a listing on the Uniterm card of the document number in a column which corresponds to its right-hand-most digit. (See sample Uniterm card) This is useful in comparing two or more Uniterm file cards.

Uniterm List

Most Uniterm systems have a list or table of Uniterms which is consulted when assigning Uniterms to documents. This is an a priori list. It is proposed that in this system this list will be developed after the system has been in operation for some time and will be derived from the terms chosen and used most frequently by the users of the system. At present it is suggested that for each reference approximately 10 words be chosen, which the user feels will be pertinent, from the reference and that about 5 will be underlined for use in the Uniterm filing. It is felt that in this way the "terms" will gradually be accumulated which will be most in the minds of those using the system. A natural list will then be chosen from the cards which will help uniformity of the system. This is preferred to forcing a list of arbitrary "terms" into our thinking. This list will be typed in alphabetical order and distributed as the need arises to all users of the system. After the system has been in use for some time, the list will be edited by eliminating duplicate, redundant and sport terms. The list will become hardened. Whenever possible, use terms on the list. Avoid using two words or hyphenated words as a single term.

Return of Uniterm Cards and Document Cards to Files

Uniterm cards are returned to file immediately after use and are not carried away from file. They are returned in strict alphabetical order. If there is any question, see secretary. Document cards are returned to file immediately after use and are not carried away from file. If necessary, secretary can have Xerox copies made of cards (2 to a sheet) for user's personal use. If it is thought to be useful to users of the file, Xerox copies of weekly acquisitions can be distributed to users weekly.

Subject Matter for File

At present any and all material relating to the Managed Energy Terrella Project 15G-B2299 will be considered subject material for the file. This will include but not be limited to the following subjects:

- Biological entities
- Responses of bioentities
- Stimuli of bioentities
- Kinds of environmental variables, such as physical, chemical, etc.
- Magnetics, gas fluids, temperature, sound, light, heat etc.
- Instrumentation to make measurements of environmental variables
- Instrumentation to record measurements of environmental variables
- Instrumentation to compute results from data of environmental variables

Books, journal articles, newspaper articles, private letters, private reports, company reports, etc. are all proper sources to be filed in this index.

Format for References

Many of the references found and used in the study will be listed in the quarterly and/or final report. It will be absolutely essential therefore that a uniform format be used in referencing all documents. The following examples are given and are to be followed where possible.

Journal A. B. Author(s), Title of Article, J. Chem. Phys., 22:1414-1453, 1954 (Author(s), title, approved abbreviation of journal, volume underlined and followed by colon, first and last pages of article, year)

Book A. B. Author and C. D. Co-author, Title of Book, Third Edition, John Wiley and Sons, Inc., New York, 1963, pp. 413-472.

(Author, "article," chapter, name of book, editor(s) ed., publisher, year, pp referenced. For books with many authors put together by an editor.

Report A. B. Author, Title of Report, Report PWD-367, Bulova Research and Development Labs, Contract DA-65742-43, April 1960

Be complete: List all page numbers, contract numbers, write out name of journal if approved abbreviation is not known, make it easy for the next person to find it.

If your document doesn't fit the above categories, come as close as you can. No author, start with title; letter? state subject, from whom to whom, date, project number etc.

Add anything useful. Things that would help if you searched. Examples: no English translation (if one, where); out of print, available from Government Printing Office, $1.50, reprinted in Reader's Digest, August 1959, etc.

If a uniform format is used it will be a simple matter to transfer this information into a report. Things are hectic enough at report time to have to worry about reference style also.

F-B2299

Document Card Example

45/D*

Meyer Sapoff and R. M. Oppenheim, A Blanket Approach to a Linear Thermistor Network, Part I the Method, Electronic Design, pp. 20-23, March 29, 1965

(Also same authors, The Design of Linear Thermistor Networks, IEEE International Convention Record, March 1964)

Thermistor	Good general article with curves and worked out examples, recommended for any thermistor work. RJG
Linearizing	
Temperature	
Sensors	
Networks	
Universal	Initials of abstracter
Generalized	
Calculation	
Formulas	
Curves	

Underlined words put on Uniterm File Cards

*Acquisition number assigned only by secretary --/D indicates document is in document file. L indicates document is in library. YXZ - initials of individual owning available copy - others added as needed

Typical Uniterm Cards

Referring to document card example, document can be found through any of these four Uniterm cards. If the four cards are examined together, it can be seen that "45" is common to all four. Therefore the four Uniterms: THERMISTOR, TEMPERATURE, CALCULATION, and SENSOR are common to that document card. Note also that article 72 and article 105 are also found on two cards.

THERMISTOR and TEMPERATURE. Note that there are 82 articles listed to which the user is directed by one Uniterm or another, but only one card, 45, which has the common Uniterms, Thermistor, Temperature, Sensor and Calculation, and only two cards 72 and 105 for Thermistor and Temperature. It is therefore useful to select several Uniterm cards with pertinent Uniterms and find the article common to several. This lowers the noise and directs the user to a <u>few</u> pertinent articles rather than to many articles remotely connected to the subject in which he is interested.

UNITERM CARD EXAMPLES (1)

THERMISTOR

0	1	2	3	4	5	6	7	8	9
10	21, 81	12, 42	23, 33	14	45	16, 36	7, 27	18, 28	9
30, 80		72,			105		107	108	19, 59
		102							

TEMPERATURE

0	1	2	3	4	5	6	7	8	9
110	81	62	63	44, 54	5, 45	57, 67	38, 98	26	79
		72, 82	103	64	55, 105				

Document numbers hand-posted by secretary on Uniterm cards
45 circled for clarity in example

UNITERM CARD EXAMPLES (2)

CALCULATION

0	1	2	3	4	5	6	7	8	9
100	41	22, 32	53, 83,	24	45 85	56, 66	97	98,	69
			93		95, 215	76		118	89

SENSOR

0	1	2	3	4	5	6	7	8	9
20	11	52		34 84,	15 35		17, 87	8	99
40		102		94	45 65				109
60		112			75				119
									129

3.11 Discussion of Analogs

In the development of a hypothesis which will eventually be tested by an experiment it is useful very often to consider an analogy to the bio-system being studied. Essentially there are two kinds of analogies. The first, or qualitative analogy, is useful for visualizing and describing for others a complicated biological process. However, one must be careful not to carry an analogy of the first type too far. An analogy of the first type generally uses a verbal description of a familiar circumstance or process to describe an unfamiliar process. An analogy of the second type, or quantitative analogy, is one where a familiar circumstance or process is described using mathematical description of the known familiar process where the mathematical description is believed to be identical (at least to the desired approximation) to that of the unfamiliar process. In other words, the two processes (physically these might be entirely different) one known and familiar, the other unknown and unfamiliar are both described by identical equations. Often, this is as far as we need go, and the literature of the known process equations is used to obtain the many ramifications of the changes in the variables of the equations. In many cases, however, while the equations can be written, it is inconvenient, time consuming, or difficult to obtain solutions in the range and variation required. This situation then leads us to a simulation. The simulation in this case is a process having equations of operation which are identical (or sufficiently identical for our purpose) to that of the process under investigation. The simulation process may be a process entirely dissimilar in all physical aspects from the original process; it may replace mass with inductance or temperature with electrical potential; it may speed up or slow down time a thousandfold, but its equations in reduced form must be identical to the process being investigated. All the parameters being correctly identified, those of interest can be varied over wide or narrow ranges, together or separately, and the output observed and interpreted. Another advantage in a simulate is that parameters which might be difficult or impossible to vary in the living organism can be varied readily over a wide range with no difficulty using simple instrumentation on the simulate. The results should be the same as if we were doing the real experiment. With a good simulation they are obtained quicker, cheaper, and often without troublesome interference from uncontrolled parameters.

Great stress has been placed on the fact that the equations of the real process and the simulation process be identical. This is the ideal situation. Sometimes, this identity cannot be totally established. In this case the simulate can still give us very valuable information which could be obtained <u>only</u> through the use of the simulate and can lead us to the rejection of many hypotheses on models of the real process which might otherwise be considered. A great saving in time and effort is achieved by avoiding false trials and trails which might otherwise be attempted.

After a fashion and in part, the MET is a simulate. The natural variation of light-dark, temperature, radiation etc. is replaced by artificially controlled and measured variations of these parameters and simulates natural conditions. It is actually a simulation where the real variables are kept real, but their variation is simulated. In this case real time must be used. For example, 24 hour rhythms cannot be studied by using 24 minute rhythms. With a full blown electronic compressed time simulation of say the diurnal rhythms we could, however, study these rhythms in, say, 24 seconds. Complete simulation of biological processes are most useful and lead to specific, practical and significant experiments which can then be attempted in an MET. The important thing to realize about a simulation is that it is not the real thing and that it generally has its limitations. This is especially true of simulations of biological experiments except those of the simplest kind, in which case a simulate is generally not necessary.

A quantitative analog is a physical simulation of one process by another process having the same mathematical description. This mathematical description is not easy to develop, but once it has been determined there are actually two choices of proceeding: one, the physical simulation and, two, solution of the mathematical equations comprising the description. In some cases it may be more economical to solve these equations directly. If they are rather complex, recourse may be had to the power and versatility of digital computers. While this is often called "simulation" it must be borne in mind that it is simply the solution of the equations describing the model of the biological process. The solution is no better than the model and the equations describing it. Within these limits, many problems have been successfully solved (3-95 through 3-103 inclusive).

It should not be overlooked that many biological mechanisms when understood may prove to be applicable to the design of instrumentation for the detection measurement of various parameters (3-1). By saying that the biological mechanism is understood we simply mean that the solutions to the equations describing at least one model of the biological mechanism adequately describe that mechanism.

In summary, we must say, that the technique of the analog and its companion, the computer simulation, should be powerful tools in the armamentarium of any life scientist. These tools when applied with caution, if nothing else, direct the life scientist to the minimum but critical biological experiment.

3.12 DISCUSSION OF A HYPOTHETICAL SHIELDED ROOM

Purely as a hypothetical example let us explore the possibilities of the construction of a room to be used as a Managed Energy Terrella. There are several layers of shielding which have to be considered. The shielding required may involve the following energies: hard radiation, radio waves, electrostatic fields, magnetic fields sound fields, vibration fields, temperature and barometric pressure variations. Suppose this room is to be situated in a locale which is "average" with respect to the above energies and that the experiments to be performed in the room require that these energies be attenuated. None of these factors can be totally eliminated but can be attenuated by many orders of magnitude.

The following listing, Table 3.12-1, shows the attenuations reasonably expected within the present state of the art and the frequency range and magnitudes which could be encountered in an "average" environment.

The construction of such a room would have to proceed from the foundation up. The structure would be layered like an onion, each layer acting as an attenuation for each energy source, See Figure 3.12-1.

The layers would probably be in the following order:

a. Vibration isolation - spring-mass and dashpots

b. Weather protection and barometric pressure change isolation - rigid walls - sealed access

c. Radiation shield - lead, paraffin, water or synthetic compositions

d. Radio waves shielding - grounded screening or copper shields

e. Magnetic shields - multiple high permeability enclosing shields

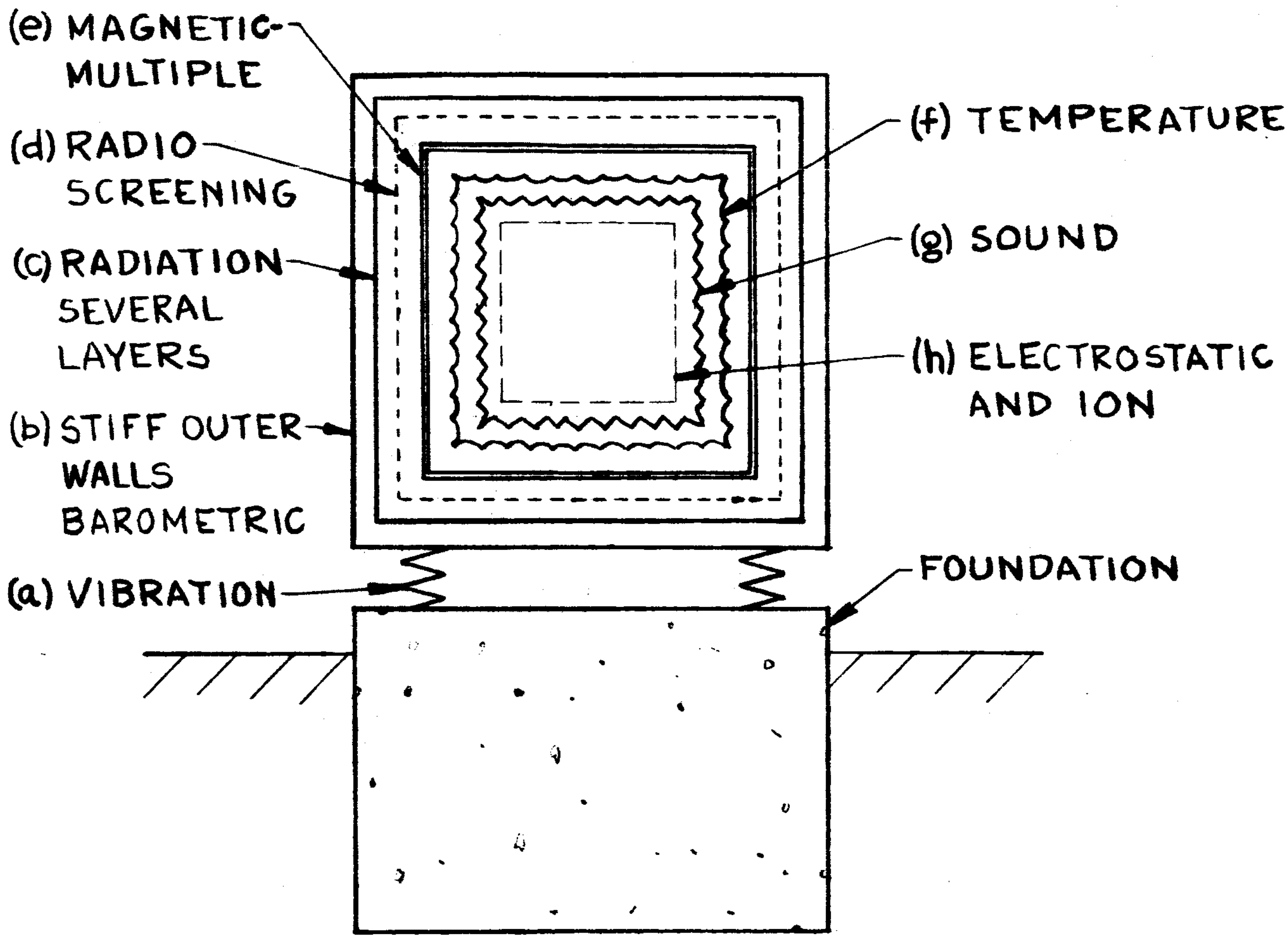
f. Temperature shielding and control - insulation and controls

g. Sound reduction - elimination of noise sources and sound deadening material

h. Electrostatic and ion shields - copper screening

Table 3.12-1

Energy Field	Amplitude and Frequency Range Approximate	Attenutation Range	Approximate Limit of Shielding
Radiation (hard)			
Radio Waves	10^{-5} volts/m to 1v/m 2×10^{4} to 10^{9} cps	$\sim 10^{3}$ to 10^{8}	10^{-8} volts/meter
Electrostatic Fields	0 to 500 volts/meter D.C., diurnal, to 1000 cps	~ 10 to 5×5^{6}	$\sim 10^{-5}$ volts/meter
Magnetic Fields	10^{-8} to 1.0 gauss max. D.C. to 400 cps	~ 10 to 10^{5}	10^{-2} to 10^{-5}
Acoustic Fields	4×10^{-9} to 4×10^{-3} μ watts/cm^{2} 1 cps to 10^{5} cps	~ 10 to 10^{3}	10^{-10} microwatts/cm^{2}
Vibration Fields	10^{-9}m to 10^{-3} meters diurnal to 10^{3} cps	~ 10 to 10^{4}	10^{-6} meters
Temperature	Outside -40°C to 50°C Inside 10°C to 40°C 0 to 6 cycles/hour max.	$\sim 10^{2}$ to 10^{4}	10^{-2} to 10^{-3} °C.
Barometric Pressure	29 to 31 inches Hg hourly - diurnal	10-100	10^{-2} mm
Ion content of air	0 to 10^{5} ions/cc usually (+)	10^{+}	~ 10 ions/cc
Gravitation		Gravity compensation by clinostat etc. 1000/1	10^{-3} g



NOTE:

EACH OF THE SHIELDS MAY CONSIST OF SEVERAL LAYERS INTERSPERSED WITH LAYERS OF OTHER SHIELDS.

Figure 3.12-1 Multi-Shielded Room

Some of these shields would consist of several layers, especially the radiation shielding, magnetic shielding and vibration shielding. Each of these would require layers designed for overlapping ranges in amplitude and frequency of the expected energies to be attenuated. The several layers of one kind of shielding may be interspersed with the several layers of another kind of shield. Rooms have been designed to shield against one or two of the energies discussed here, but a room shielding against more than two energies has, as far as we know, not been designed. Two critical points which must be considered are the means for entrance to such a shielded enclosure and equipment and means of providing power to, and information from this equipment and the bioentity under study. The first, entrances, require careful design of the doors or other ports leading to the enclosure. Generally, this is a weak point in the shielding construction of any enclosure and a good job of shielding at the ports leads to unavoidable expense and complexity of the enclosure. The second, the handling of equipment lines, power lines and data handling lines is not as straightforward a problem and each item must be treated separately. It may be necessary in some cases to use non-electric means of power, light and communication such as pneumatic, hydraulic lines and chemical illumination. Each electrical line must be carefully shielded as must each piece of electrical equipment used inside such an enclosure. No new equipment can be introduced into the enclosure until it has been individually and carefully checked out for its own contribution to the environment.

Even with all the precautions mentioned above it will probably be necessary to provide local and individual shielding for the experiment specimen to eliminate residual energy fields existing after the "general attenuation" provided by the room. However, the individual shielding will have been made much easier because of the more or less low ambient and standard conditions produced by the "general attenuation" of the multi-shielded enclosure.

Because of the various types of shielding required there will not be an efficient use of volume. The useful volume may be only 1/10 or even 1/20 of the total volume occupied by an enclosure shielded against the static and dynamic energy fields under consideration here.

Probably the best procedure in the construction of such a room would be to test each layer or set of layers as to its effectiveness in attenuating the specific energy field during construction. It would be quite difficult to make changes in an intermediate layer once the construction had been completed. This is especially true in the construction of an initial unit. At present there is sufficient uncertainty in the construction of a shield for a single energy field that it will probably be necessary to build some test rooms for single parameter shielding in order to obtain data for design purposes.

No interaction between the shields for the various energy fields is expected except in a positive way. For example temperature shielding will also serve as acoustic shielding and vice versa. Magnetic shielding will provide shielding against both r.f. and electrostatic fields but not generally vice versa. R. F. shielding will provide some attenuation of rapidly changing magnetic fields. Hard radiation shielding may or may not, depending on its nature, provide some construction rigidity against barametric variations and some temperature and acoustic shielding. Advantage can be taken of these multipurpose shielding properties.

In general, the means and technical know-how for providing the desired attenuations to the various energy fields are available. An extensive theoretical or testing program is not required. However, these techniques have not as yet been <u>combined</u> to provide a region in which the <u>several</u> energies under consideration have all been attenuated with an effectiveness permitted by the present state-of-the-art. There will be practical problems in making this combination, but these problems will not be insurmountable. It is expected that the advantages to be derived from this combination will be great. At present, nothing of this nature exists, and consequently no biological experiments have ever been performed under conditions as precise and as well controlled as will be possible if an enclosure of this nature is constructed.

There are two problems yet to be considered before an enclosure of this nature is valuable to the biological experimenter.

One is the problem of reinserting energy fields of the desired magnitude and stability, and two is the monitoring of those energy fields which cannot be attenuated or controlled.

3.13 DISCUSSION OF INTRODUCTION OF FIELDS INTO AN MET

In considering the various energy fields controlled in an MET three phases of management are involved. These three phases are: elimination or reduction, monitoring and reinsertion of these energies. In general, those energies which can be controlled are best handled by complete removal of naturally occurring variations and reinsertion of those energies in known and predetermined amplitude time dependence and direction.

A partial listing of energy fields which might be considered is the following:

Radiation (hard-x-ray-gamma rays)

Radio waves

Electrostatic fields

Magnetic fields (steady and varying)

Acoustic

Vibration fields

Temperature

Light

Barometric pressure

Ion content

Gravitation

Let us initially consider magnetic fields. First the earth's magnetic field should be reduced by appropriate shielding (See Section 3.8) to a small value (i.e. small compared to the fields to be introduced and small compared to fields which are expected to have an effect). In this region a magnetic field is then introduced by appropriate means. This means may either be by current conducting coils (air or iron core electromagnets) or permanet magnets. There is absolutely no difference between the static magnetic fields produced by these two means. However, it may be much more convenient or economical to produce the magnetic field by one method rather than another. For example, a large volume, low magnitude field can readily be produced with a large air core coil which could be difficult to do with a permanent magnet. Another factor must also be taken into consideration, that is, time dependence. If it is desired to have a time varying field (sinusoidal, square wave, impulse, etc.) or a position varying field (rotation in space etc.) this is also not difficult to do with air core coils and the appropriate electronic circuitry. In addition, it is fairly easy to design coils to produce fields with the desired uniformity and intensity over the experimental region. Methods for doing this are available in the literature (3-60, 3-104 - 3-110 inclusive). Once the geometry of the coil is fixed and a few accurate measurements of the field made, reliable predictions can be made for various current levels through the coils. Certain precautions have to be taken, however. Changing the location or amount of permeable material in or around the coils will change the distribution and intensity of the magnetic field. Further, if the field desired is a rapidly changing field, conducting materials in or around the coil will also affect the field. If an instrument is introduced to measure the field or the field of some other variable such as light, temperature, etc. this instrument may well distort the magnetic field present or introduce components of its own. The total situation must be kept in mind at all times. The interaction, if any, of the magnetic field introduced and the shield used to eliminate the ambient field must also be considered. Coils or magnets which are of comparable dimensions to the shield will distort the fields produced by the magnets or coils. Further, the fields may sufficiently saturate the shields so as to change their permeability and thus change their shielding property. As a very general rule of thumb, we can say that in the case of magnetic fields, the dimensions of the coils or magnets should be large compared to the biological specimens, and the shields should be large dimensionally compared to the coils or magnets. In general, this will lead to smaller unwanted interactions and simplify the measurements and design calculations.

Another variable which is frequently shielded against and reinserted is light. Some precautions must be taken in the reinsertion of this variable. The characteristics of light may be stated as intensity, spectral distribution (color mixture) and duration. In considering duration, we can insert the light as a single pulse of intensity or many pulses, as a step of intensity, as a square wave with a constant duty cycle or a variable duty cycle,and finally the intensity may be made a smoothly varying function of time. Both tungsten incandescent bulbs and fluorescent lights become lower in intensity with time. Fluorescent bulbs may lose 30% of their intensity in a few months time. Their spectral distribution also changes with time. Knowing the rates of change, this variation can be compensated for by working out in advance a schedule for mixing old and new tubes and thus obtain an average at any time which varies little from that at any other time. It is also necessary to consider the effects of voltage variation on the brightness and spectral distribution of the lamps. Cyclic variation of the laboratory voltage supply due to high usage during the day and low load at night or over weekends may introduce a cyclic variation into supposedly constant intensity or constant spectral content. This in turn could synchronize a biological rhythm. Even though the effect of temperature on most biological rhythms is small, the heating effect of the lamps should not be disregarded. An effect until the present generally disregarded is the magnetic fields produced by the currents through the lamps and their wiring (See 3.8). Sound from fluorescent ballasts (a 60 and 120 cycle hum) should also be kept in mind. In reintroducing light which is similar to that of natural lighting, account must be taken of the changing spectral content at different altitudes, latitudes, time of day and condition of the atmosphere (3-111). When looked at in this way the simple problem of reintroducing light into a biological experiment becomes not so simple.

Until it can be shown that the results of any of the possible variations in the artificial light are negligible, these variations should be monitored or controlled.

Any field that is to be introduced into an MET will have its own peculiar problems. When carefully investigated it will generally be found that many factors contribute to small random variations or cyclic variations which at first glance either are not noticed or appear harmless to the integrity of the experiment. With the critical experiments being done today and those projected for the future, it is only good common sense to thoroughly consider all of the possible variations which can occur in the reintroduced variables and <u>their possible interactions</u> with other introduced variables. Once these variations and interactions are recognized, means for monitoring or eliminating them must be considered. In general, this phase of the problem will not require any new technology.

3.14 CONCLUSIONS AND RECOMMENDATIONS

In summary, we have looked at the problem of carrying out a biological experiment. We have come to the conclusion that all experiments in the life sciences can have in common the requirement of controlling the energy inputs to the subject and measuring the energy outputs from the subject. Where this requirement cannot be met, the next best thing to do is to monitor (rather than control) the energy inputs. These inputs and outputs carry information and this information can be described as flowing in a closed loop through the biological subject and the experimenter. This information flow loop can be described by means of a diagram. This diagram showing the flow of information helps the experimenter visualize the points through which the information flows and the interfaces of the information flow. Further it allows him to characterize and concretely describe interactions between nodes which can create false or spurious information. Several of these nodes, interfaces and interactions were studied in some detail. Time did not permit a complete evaluation of all of them. The important progress which has been made is that all nodes, interfaces and interactions can now be placed into one scheme or diagramatic representation showing their relationships to each other and to the experiment as a whole.

In order to implement this scheme a Managed Energy Terrella (MET) has been proposed as the general name and practical environment in which a biological experiment can be carried out. Of necessity, this MET, as visualized for any particular kind of experiment becomes specific in its implementation. It does, however, remain general in that it attempts to take into consideration more and better control or monitoring of the various energy inputs to the biological subject and includes means for measuring within practical limitations the outputs of that subject.

Specific details of control of some energies have been worked out and a compilation of the ranges of energies for many organisms has been started.

The work completed so far should be useful to many experimenters. Much remains to be accomplished, however, in developing information about each of the nodes, interactions and interfaces. At the same time, design procedures must be developed for specific measurement, monitoring, shielding and control techniques.

It is felt that a good beginning has been made and that a clear path now lies ahead which when travelled will prove rewarding.

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APPENDIX

MANAGED ENERGY TERRELLA

ENVIRONMENTAL PARAMETERS AND BIOLOGICAL INTERACTIONS

MANAGED ENERGY TERRELLA
ENVIRONMENTAL PARAMETERS AND BIOLOGICAL INTERACTIONS

The branch of biological sciences dealing with the relations of organisms to environment is known as ecology. Like many of the other biological sub-disciplines its total scope is somewhat indefinite because most of the phenomena exhibited by plants and animals can be related to the environment in some way. Basically, nearly all of these phenomena are physiological, hence the relations to the environment are physiological, but ecology is quite distinct from physiology. Ecology deals with those physiological properties which have importance in the natural environment. Although unnatural or contrived environmental extremes may be of physiological interest, they are not of concern in the present investigation since, in this case, the fundamental orientation embraces only natural environmental parameters and their limits.

The importance of studying environmental factors has been pointed out by Kinne (23), who brought attention to the fact that experimental results in the natural habitat (biotope) are often quite different from those obtained under artificial laboratory conditions. This distinction forms the basic rationale of the present study. By determining what the parameters may be that compose the natural habitat (or environment), artificial laboratory conditions can be made to include more of these factors than previously, or at least be cognizant of what is lacking.

Living organisms, regardless of biological classification or size, spend their entire lives interacting with each other and with their environment. The one most predominant feature of this interaction is the exchange of energy. The flow of energy into and out of these environments must be a critical condition for the existence and propagation of life itself. Since biology is a complex subject composed of many variables, experimentation with complete control over these variables has been difficult, if not impossible. Because of the complexity of the living organism and the multiplicity of its interactions, an analysis of these interactions may be helpful in understanding the energy exchanges that transpire. As pointed out above, living organisms interact with each other and with their environment. Therefore, each living organism is subjected essentially to two environments: a biotic environment and a physical environment. The physical environment will be considered first.

The Physical Environment may be considered as being composed of two divisions, terrestrial and aquatic. Each contains the same general variables but with additional parameters that are peculiar to each specifically. The environmental variables that may be encountered in the aquatic environment are listed as follows:

Temperature variations
Salt concentration
Conductivity
pH
Viscosity and changes in state
Pressure, barometric, depth
Turbidity
Turbulence
Currents and tides
Chemical constituents and gases
Seasonal and daily changes (all inclusive), synergies
Volume changes relative to organisms
Illumination-intensity and wave length
Evaporation
Shelter and protection
Terrain
Radiation
*Ionization
*Energy fluxes - RF, magnetic, electrical
Vibration
Gravity
*Telluric currents
Time

The terrestrial environment includes the following variables:

Atmosphere
Gases
Humidity
Temperature
Pressure
Illumination - intensity
- wave length
Radiation
Ionization
*Air flow and turbulence
*Energy fluxes, magnetic, RF, electrical
Gravity
Vibration
Terrain
Shelter and protection
Sound
Seasonal and daily changes
Meteorological changes
Habitat variations
*Friction
*Physical cycles, sun spots
*Telluric currents
Time
Macro-, micro-climate relationships
*Dew-point
*Ground conductivity
Convection
*Condensation
*Albedo
*Latent heat
*Reflected energy
*Dust particles
Emissivity
Vector effects - synergy

*Indicates those parameters for which little or no data are available on biological effects.

DATA, VARIABLES IN THE PHYSICAL ENVIRONMENT

TEMPERATURE (43)

World extremes -90°F. to 136°F.

U. S. extremes -66°F. to 134°F.

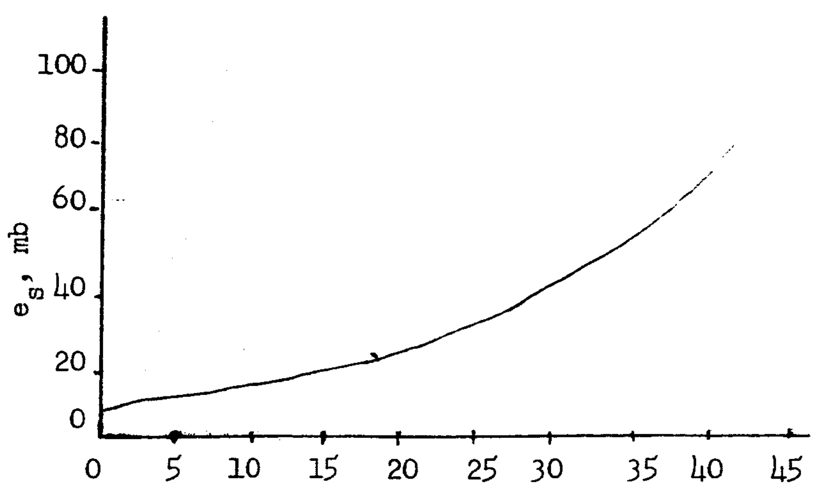
Biotic limits -40°C. to 60°C.
(These limits are extremes of cold death to heat death.)

Optimal biotic range 15°C. to 38°C.

HUMIDITY (33)

Humidity per se is a meaningless measurement since it is so closely dependent upon temperature. A more realistic value would be an "index" which is based upon per cent relative humidity and temperature. Relative humidity is dependent upon air temperature as well as the vapor pressure, e, because e varies markedly with temperature. There are, however, seven ways of expressing atmospheric humidity. These are the following:

(1) Vapor Pressure - Dalton's law of Partial Pressures is used when defining the vapor pressure of the water vapor in the air, represented by e and measured in millibars. The saturation vapor pressure, e_s, is the pressure of the water vapor when it is in equilibrium with a plane surface of water or ice at the same temperature. The relationship between e_s and temperature, T, is illustrated in the following graph. Thus, air at 30°C. will need about three times as much water vapor before becoming saturated as air at 12°C.



Temperature, °C. (Platt & Griffiths, p. 146)

(2) Saturation Deficit - The difference between actual vapor pressure, e, and the saturation vapor pressure, e_s, at the same temperature.

(3) Relative Humidity - Percentage degree of saturation, $100\ e/e_s$, being a dimensionless value and less than or equal to 100, except in rare circumstances.

(4) Dew Point - The temperature at which further cooling would cause dew formation or condensation if a surface or nuclei were available. For saturated air, the temperature and dew point are equal.

(5) Absolute Humidity - The density of the water vapor present in the atmosphere expressed as the mass per unit volume of air, generally gm/m^3. The equation for absolute humidity, X is

$$X = 217e/T$$

where e is in millibars, T in ^oK.

(6) Specific Humidity - The mass of water vapor per unit air mass. If q is specific humidity, p is total air pressure, then

$$q = 0.622\ e/(p - e + 0.622e)$$

since the molecular weight of water vapor is only 0.622 times that of dry air. This may be reduced to

$$q = 5\ e/(8p - 3e)$$

(7) Mixing Ratio - The mass of water vapor is referred to the unit mass of dry air so that the mixing ratio, $w = 0.622/(p/e - 1)$. It may be noted that w is greater than q, although for many purposes the two may be equated.

$$q = w/(1 + w) \text{ or } w = q/(1 - q)$$

Relationship Between Temperature, Relative Humidity and Vapor Pressure (15)

Relative Humidity	Vapor Pressure Values (In Millibars) — Temperature $0^{\circ}C$	$10^{\circ}C$	$20^{\circ}C$	$30^{\circ}C$	$40^{\circ}C$	$50^{\circ}C$
100%	6.1	12.3	23.4	42.4	73.8	123.4
50%	3.1	6.2	11.7	21.2	36.9	61.7

ATMOSPHERE (43)

Gas	Terrestrial	Aquatic — Sea Water	Fresh Water
O_2	20.99 vol.%[1]	0.58 vol. %	0.72 vol. %
CO_2	0.03	0.02	0.03[3]
N_2	78.03	1.03	1.33[3]
H_2O	1.00[2]	--	--
Salts	--	3.46	0.18
pH	--	7.5 - 8.4	3.2 - 10.6
Inert gases	0.95	Trace	Trace

1. STP, per cent varies with altitude and temperature
2. Varies, but is never absent and always biologically significant
3. At $15^{\circ}C$.

Viscosity Coefficients for Water and Air as a Function of Temperature (15)

Temperature $^{\circ}C$.	Viscosity, in Poises — Water	Air
0	1.792×10^{-2}	$1\ 71 \times 10^{-4}$
20	1.005	1.81
40	0.656	1.90
60	0.469	2.00
80	0.357	2.09
100	0.284	2.18

Pressure (43), Sea Level[1]—760 mm Hg (STP)

Gas	Terrestrial	Aquatic: Sea Water	Aquatic: Fresh Water
O_2	159.52 mm Hg	159.52 mm Hg	159.52[5] mm Hg
CO_2	0.23[2]	0.23	0.23[5]
N_2	593.02	593.02	593.02[5]
H_2O	6.40[3]	12.79[4]	6.10[6]
Inert Gases	7.46	7.46	7.46

1. Air density at sea level = 1.2 g/L (0.0012)
   Sea water density at sea level = 1027 g/L (1.027)
   Fresh water density at sea level = 1000 g/L (1.00)
2. This value is variable, varying with atmospheric and environmental conditions.
3. At 50% relative humidity
4. At 15°C.
5. At STP but varies widely depending upon partial pressures of the dissolved gases.
6. At 4°C.

	Sea Water[1] (43)
Salt concentration	35 (33-37) g/Kg
pH surface	8.1 - 8.3
depth	7.5 - 8.1
Density	1.02 - 1.03
Temperature	-1.5°C to 30°C
Freezing point	-2°C
Specific heat	0.93 cal/g[2]
Sound velocity	1450 - 1550 m/sec.
Transparency[2]	66 m
Hydrostatic pressure[3]	1 atm/10m

1. Standard chlorinity = 19 which equals a salinity of 34.325 g/Kg
2. Using a 30 cm Secchi disc
3. Increases 1 atm for each 10 m depth

Composition of Sea Water[1] (43)

Anions	Value	Cations	Value
Chloride	18.98 g	Sodium	10.56 g
Sulfate	2.65	Magnesium	1.27
Bicarbonate	0.14	Calcium	0.40
Bromide	65 mg	Potassium	0.38
Fluoride	1.3 mg	Strontium	13 mg
Boric acid	26 mg		

1. Based on total salinity of 34.325 g/Kg

Composition of Sea Water (43)

Element	Value	Element	Value
Cl	18.98 g	Zn	5 µg
Na	10.56	Pb	5
Mg	1.27	Se	4
S	0.88	Cs	2
Ca	0.40	U	2
K	0.38	Mb	0.7
Br	65 mg	Ga	0.5
C	28	Th	0.4
Sr	13	Ce	0.4
B	4.6	Ag	0.3
Si	0.02 - 4.0	V	0.3
Fl	1.4	La	0.3
N	0.006 - 0.7	Y	0.3
Al	70 µg	Bi	0.2
Rb	0.2	Ni	0.1
Li	0.1	Si	0.04
P	1 - 100	Hg	0.03
Ba	54	Au	0.004
I	50	Ra	0.2-0.3 x 10^{-10} µg
As	10 - 20	Cd	present
Fe	2 - 50	Cr	present
Mn	1 - 10	Co	0.1
Cu	1 - 10	Sn	3

METEOROLOGICAL CHANGES (43)

Annual Rainfall

World extreme - 460.2 inches

U. S. extreme - 29.0 inches

Minimum average rainfall - 1.35 inches

Mean Temperature (Northern Hemisphere)

30° N. Lat. - $20.4^{\circ}C$ ($69^{\circ}F$)

45° N. Lat. - $9.8^{\circ}C$ ($50^{\circ}F$)

60° N. Lat. - $1.1^{\circ}C$ ($30^{\circ}C$)

Dirunal Cycles[1] (Northern Hemisphere) (43)

	Dec. 21	Jan. 21 Nov. 21	Feb. 21 Oct. 21	Mar. 21 Sept. 21	April 21 Aug. 21	May 21 July 21	June 21
30°N. Lat.	10.2/13.8	10.4/13.6	11.1/12.9	12.0/12.0	12.9/11.1	13.6/10.4	13.8/10.2
40°N. Lat.	9.3/14.7	9.7/14.3	10.6/13.4	12.0/12.0	13.4/10.6	14.3/9.7	14.7/9.3
50°N. Lat.	8.0/16.0	8.6/15.4	10.1/13.9	12.0/12.0	13.9/10.1	15.4/8.6	16.0/8.0

1. Hours day/hours night

Sunlight (15,33,43)

Cloudy, overcast - 200 ft. candles

Clear, at noon - 14,000 ft. candles

Moonlight - full moon, maximum - 0.05 ft. candles

Light penetration in water - 30% at 5 m depth

10% at 10 m depth

ENERGY FLUXES

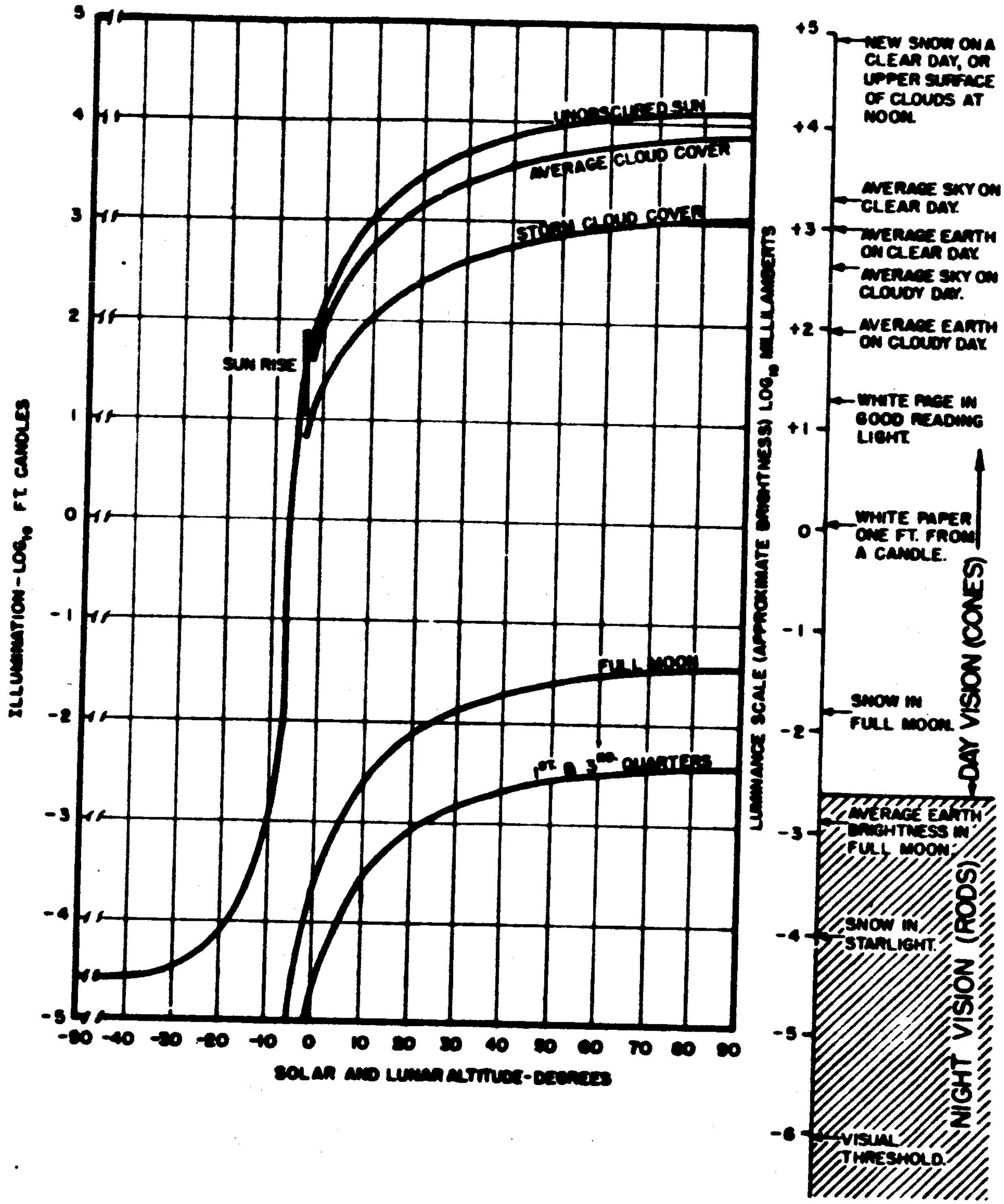
Natural Ionizing Radiation (36)

Location	Dose Rate
Igneous rock	145 mr/yr
Sedimentary strata	78
open ocean	55

Ionizing Radiation of Natural Radioactivity of Living Matter (36)

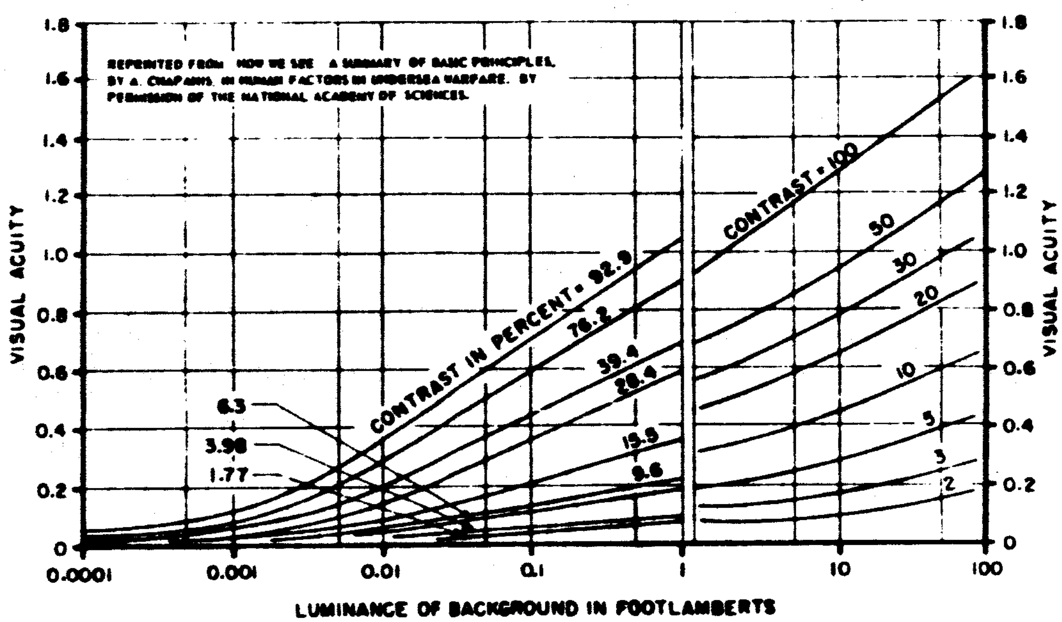
Tissue	Radium Content
Bone	9.7 g x 10^{15}/g fresh tissue
Lung	2.3
Liver	3.4
Muscle	1.4

EARTH ILLUMINATION AND BRIGHTNESS (50)



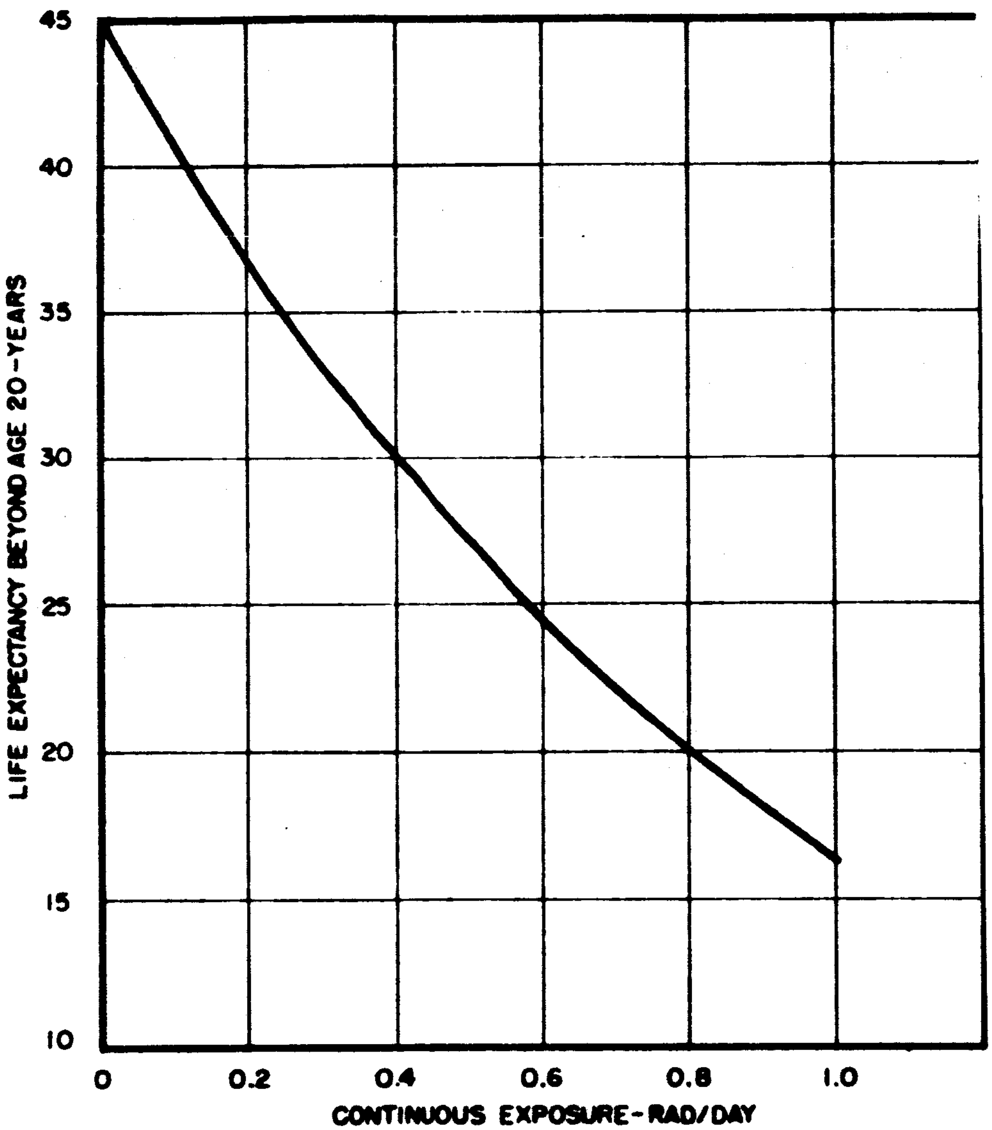
The range of natural illumination on Earth from the sun and moon (in $\log_{10}$ foot candles) as the values increase from minimum before sun- or moonrise to maximum at the zenith. The scale to the right of the illumination graph shows a matching luminance (approximate brightness) scale in $\log_{10}$ millilamberts, with a number of commonly experienced brightness levels keyed to it. (Adapted from U. S. Navy data on illumination.)

VISUAL ACUITY AND CONTRAST (50,52)



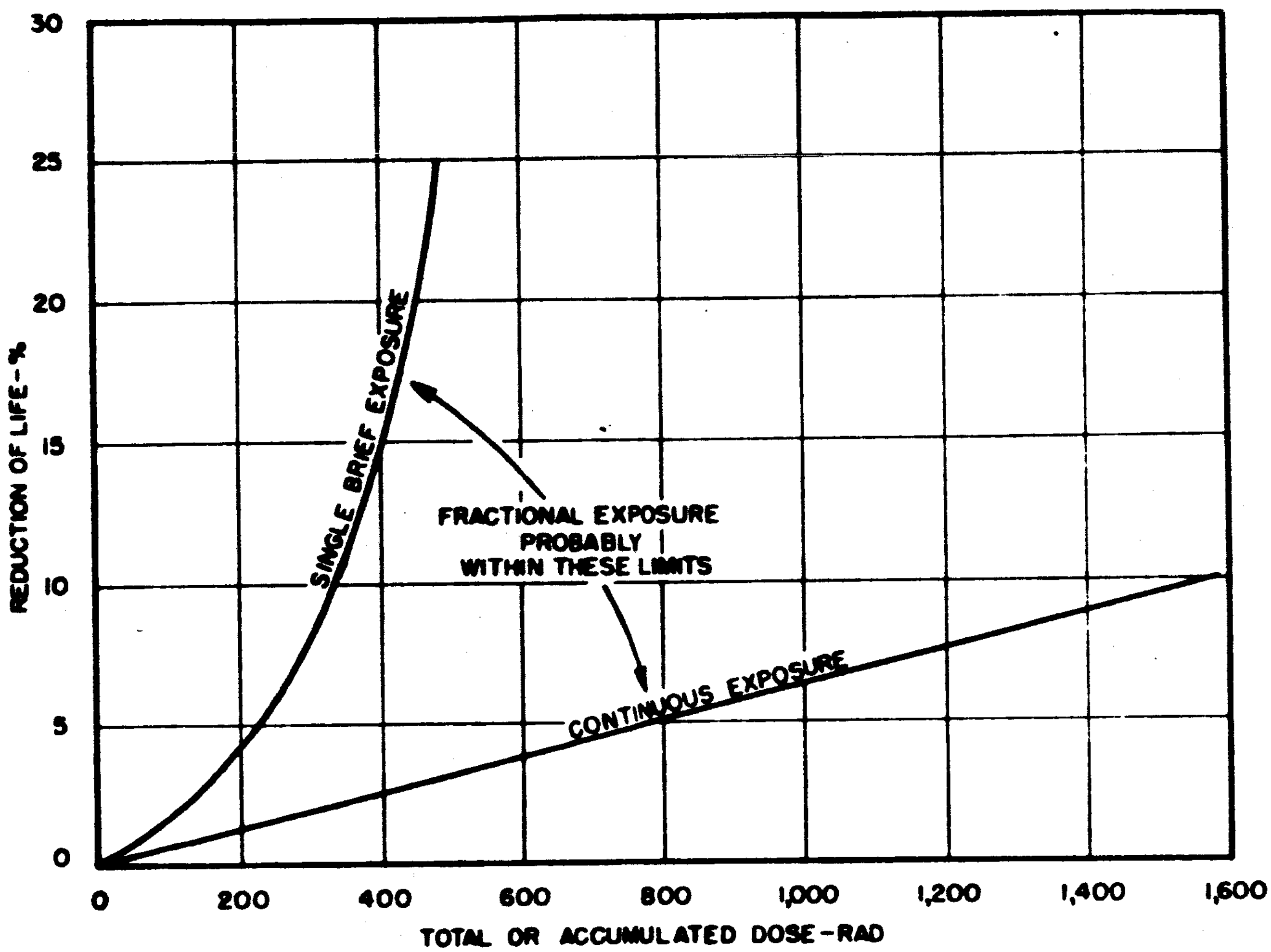
Visual acuity as a function of background luminance and luminance contrast between the object and its background.

RADIATION AND LIFE EXPECTANCY (50)



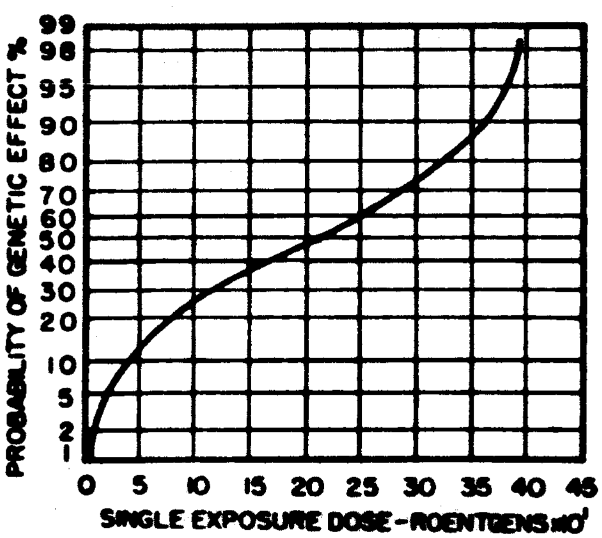
The estimated life expectancy of a 20-year-old population exposed to fixed daily doses of whole body radiation, continued until time of death. Deaths would be from all natural causes, not from leukemia and other illness related to radiation. In fact, comparisons have been drawn between the effects of radiation and the normal process of aging. (Compiled by Webb Associates, 1962.)

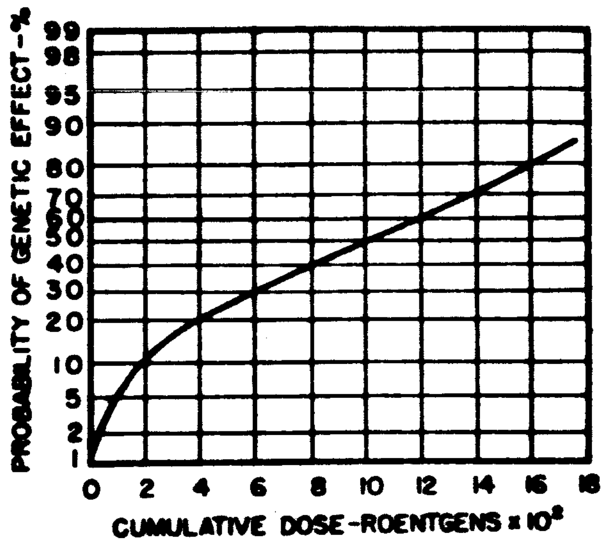
LIFE SHORTENING FROM RADIATION (50)



A comparison of the effects of brief single doses with continuous exposure to whole body radiation, on the shortening of life due to radiation. Multiple brief exposures, separated by days or weeks, termed fractionated exposures, will be expected to have an effect somewhere between the limits shown for single and continuous exposure. (This chart and the previous one are based on animal work, since there are no human data. Compiled by Webb Associates, 1962.)

LONG TERM EFFECTS OF RADIATION (50)





In addition to the life-shortening effect where death is from all ordinary causes, radiation is followed by an increased incidence of leukemia and by damage to the genes of the reproductive cells.

The leukemia effect is given as a probability of

$$10^{-6}/r/yr$$

for at least the first 20 years after brief exposure to whole body radiation. (Based on Atomic Bomb Casualty Commission data collected in Japan.)

The genetic effect is expressed as a probability of

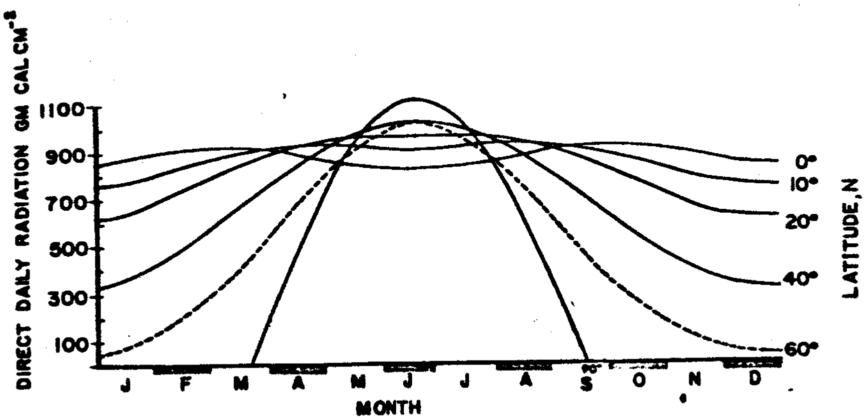
$25 \times 10^{-8}/r/gene$, for males, brief exposure; and

$5 \times 10^{-8}/r/gene$, for males continuously exposed.

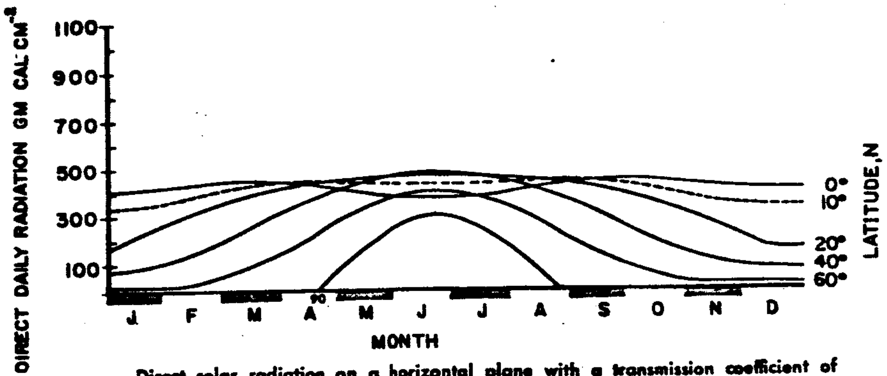
These are based on mouse experiments showing recessive visible mutations produced by irradiation of spermatogonial cells. Man is expected to have genetic effects fairly close to these in mice. If he has from 10^4 to 10^5 genes per germ cell, then the probability of genetic effect would be approximately what is shown in the above two graphs.

Direct Solar Radiation by Latitude and Month (33)

Solar constant = 2.0 gm cal cm^{-2} min^{-1}



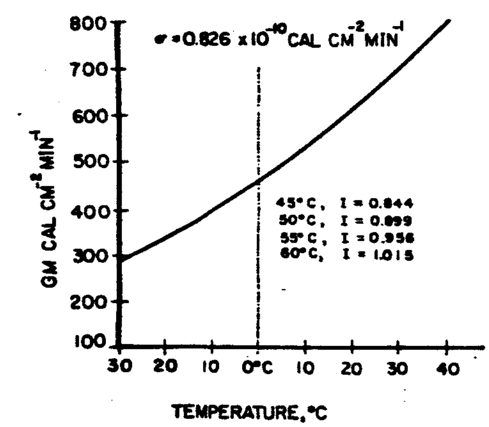
Direct solar radiation on a horizontal plane with a transmission coefficient of 1.0. The solar constant is 2.0 gm cal cm^{-2} min^{-1}. (33)



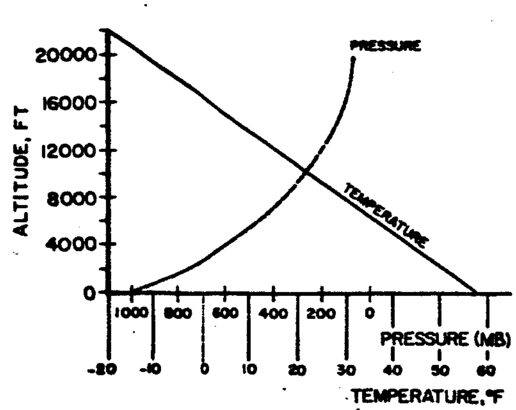
Direct solar radiation on a horizontal plane with a transmission coefficient of 0.6. The solar constant is 2.0 gm cal cm^{-2} min^{-1}. (33)

Thermal Absorptance and Heat Capacity (33)

Substance	Thermal Conductivity BTU/hr ft/°F.	Heat Capacity BTU/ft²/°F
Dry Air (1 atmosphere)	0.015	0.018
Fresh Snow	0.05	3.42
Dry peat soil	0.03	4.6
Coarse sand	0.25	17
Water	0.33	62
Asphalt slab	0.86	28
Sandstone	1.1	31
Ice	1.3	29
Copper	224	52



Black body radiation, *I*, as a function of temperature. (33)



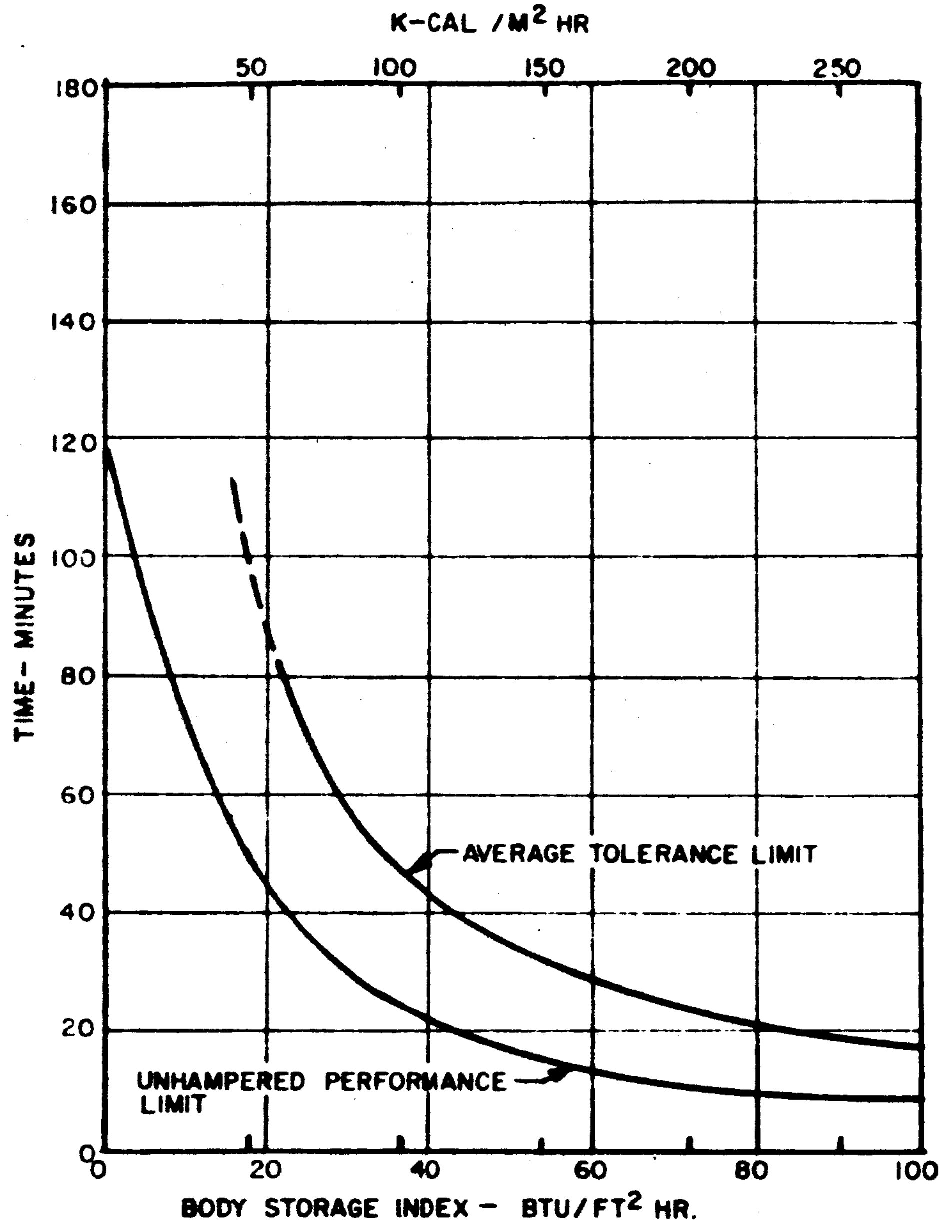
Relationship of altitude with pressure and temperature for N.A.C.A. Standard Atmosphere. (33)

THERMAL RADIATION REGIMES FOR HYPOTHETICAL ENVIRONMENTS (15)

Condition	Air Temp at Surf. °C.	Surf. Temp Ground °C.	Albedo %	Vapor Pressure mb	Solar Sky	Refl. Solar	Downward Longwave	Upward Longwave	Net Flux	Total Absolute Flux	Absorption by Horizontal Leaf
					CAL PER CM^2 PER MIN.						
Sand Dunes											
Clear Day	30	40	30	36.1	1.0	-0.30	0.556	-0.792	0.464	2.648	2.400
Cloudy Day	30	30	30	36.1	0.57	-0.17	0.666	-0.696	0.370	2.102	1.946
Clear Night	15	10	-	15.2	-	-	0.434	-0.528	-0.094	0.962	0.932
Cloudy Night	15	15	-	15.2	-	-	0.534	-0.557	-0.023	1.091	1.058
Open Clearing in Forest With Grass											
Clear Day	30	40	7	36.1	1.0	-0.07	0.556	-0.792	0.694	2.418	2.210
Bog with Lake											
Clear Day Over Water	30	25	9	36.1	1.0	-0.09	0.556	-0.643	0.823	2.289	2.089
Over Mat	30	40	2	36.1	1.0	-0.02	0.556	-0.792	0.744	2.368	2.167
Interior Deciduous Forest	T^1 crowns										
Clear Day	23	20	-	-	0.05	0	0.637	-0.607	0.080	1.294	1.247
	35	30	-	-	0.05	0	0.738	-0.696	0.042	1.484	1.431

1. T = temperature

THERMAL TOLERANCE LIMITS (4,50)

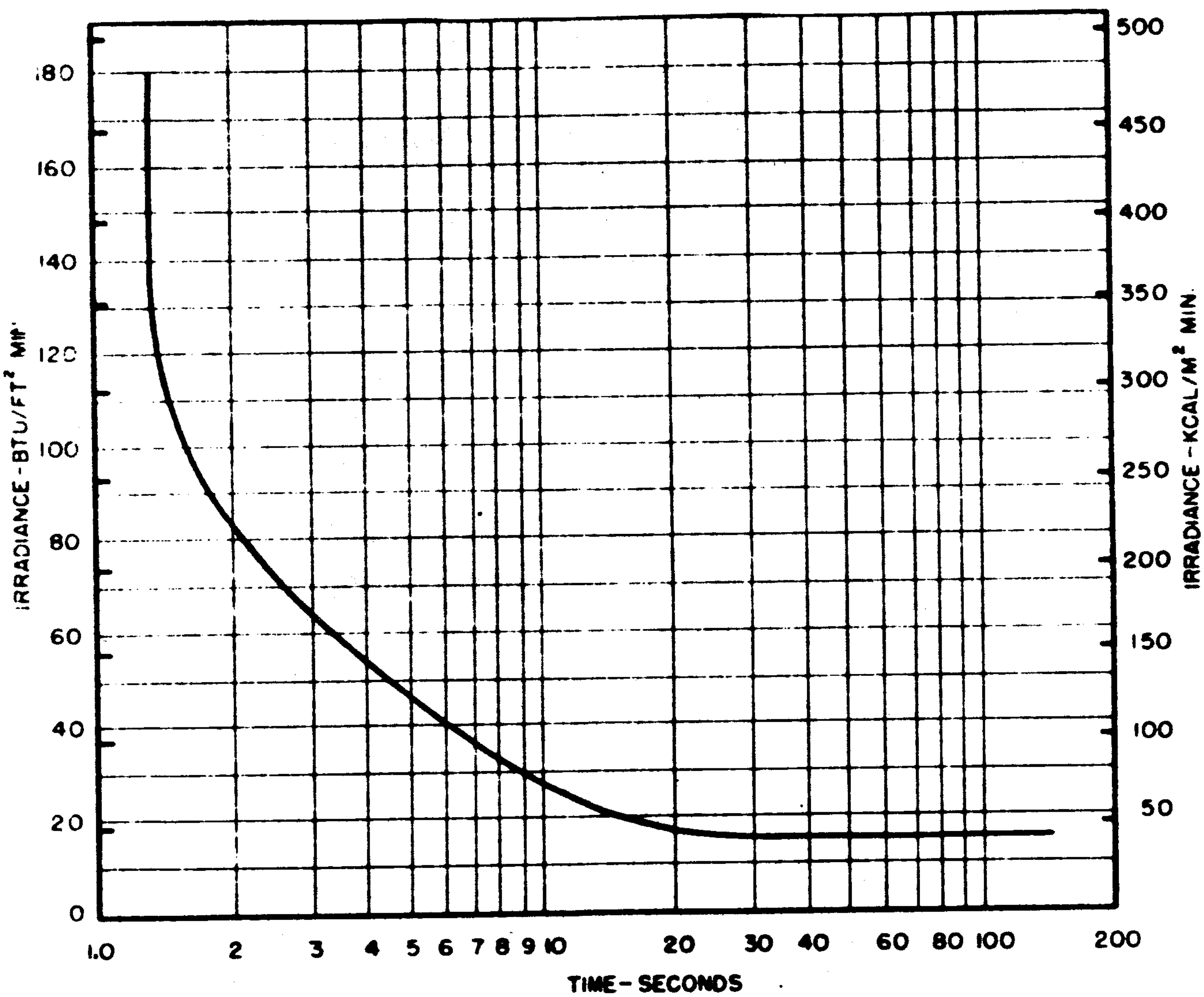


Tolerance limits which define impairment in performance and the physiological endpoint for severe heat exposures which produce storage of body heat. Body storage rate (q_s) is computed from the change in average skin temperature (t_s), rectal temperature (t_r), and the body mass (W), surface area (S. A.), and specific heat (= 0.83) according to the formula

$$q_s = 0.83 \frac{W}{S.A.} \times \frac{.33\Delta t_s + 0.67\Delta t_r}{hrs}.$$

English units (lbs, ft^2, ^{o}F) give the answer in Btu/ft^{2}hr, and metric units (kg, m^2, ^{o}C) give the answer in kcal/m^{2}hr. Storage of heat occurs in those severe exposures (usually above 120^{o}F) where the body's physiological mechanisms are unable to compensate for the heat load and metabolic heat. The tolerance limit in storage is reached when approximately 80 kcal/m^{2}hr has been stored, and the subject is on the verge of clinical heat stroke.

PAIN FROM RADIANT HEAT (4,18,44,49,50)



Time to reach strong skin pain from radiant heating, with radiation sources ranging from the simulated intense thermal flash of a nuclear weapon (approximately 100 Btu/ft^2min) to the slow heat pulse associated with reentry heating, where the heating is partly convective as well. The curve is derived from experiments involving heating of single small areas of forehead or forearm, of exposed areas of skin of a subject in flight clothing, and of the whole body surface.

The curve becomes asymptotic at about 18 Btu/ft^2min, which means that at this level and below, the blood supply to the skin is carrying off the heat as fast as it arrives, and heat is stored in the body.

Sound Pressure Levels of Common Noises (50)

Pressure Dynes/cm^2	Sound Pressure Level db	
	160	Mechanical damage
10,000		
	140	Pain threshold Rocket engine Jet engine Thunder clap
	120	Discomfort threshold
100		Artillery fire, B-25 at 180 mph Rumble of thunder, subway train from platform Riveter at 35 feet
	100	Noisy factory Subway car interior Automobile
	80	Heavy traffic noise
1.0		Noisy Office
	60	Typical office
	40	Average living room, or quiet office
0.01		
	20	Very quiet room
0.002	0	Threshold of detectibility

Gravitational Tolerance (Man) (43)

Duration of G Force*	Time in Seconds 0.001	0.01	0.1	1.0	10.0	100.0	1000.0
+ G	70	30-40	19-22.5	12.5	6.5-8.2	3.5-5.5	3.5
- G	15	9.5-16.5	6.5-10	4.5-6.5	3.2-3.8	3.2-2.5	1.5
Transverse G	200	60-100	38-55	25-27.5	15-17.5	7.2-12.5	8.5

* +G = force vector parallel to long axis of body, from foot to head

-G = force vector parallel to long axis of body, from head to foot

Transverse G = force vector perpendicular to long axis of body, chest to back or back to chest

Gravity (32)

Newton's law of gravitation states that the force (in dynes) between two point masses m_1, m_2 equals Gm_1m_2/r^2 where r is the distance between the masses and $G = 6.670 \times 10^{-8}$ $\left[\approx (20/3) \times 10^{-8}\right]$ $cm^3/g - s^2$. In calculating earth's gravitational field, the centrifugal force due to the rotation of the earth must be taken into account. The earth may be considered an ellipsoid of revolution with an ellipicity (equatorial minus polar radius divided by equatorial radius) = 1/297. The force of gravity, by definition, is everywhere perpendicular to the surface which means it acts in the vertical direction. Its variation with the latitude ϕ, at sea level, can be approximated by the formula** $g = 978.049\ (1 + 0.0052884 \sin^2 \phi - 0.000005 \sin^2 2\phi) cm/s^2$.

**The formula adopted by the International Union of Geodesy and Geophysics in 1930 and based on absolute g-value of 981.274 cm/s^2 measured in 1906 at Potsdam.

Gravity anomalies are expressed in milligals. The gal is the cgs unit of acceleration (1 cm/s^2). Since the value g given above varies between 978.049 and 983.221 gal from equation to poles, one milligal is roughly one millionth of the normal gravity at any place on the earth. The maximum gravity anomalies (on the surface) due to concealed features such as salt domes, oil bearing structures, ore bodies, undulations of rock strata, etc. seldom exceed a few milligals and are often only a fraction of a milligal. Away from such maxima, the distortions in the normal gravity field of the earth will be even smaller, one to ten parts in 10^8.

Electrical Phenomena (32)

Electrical energies produced within the earth may be measured by (a) self-potential and (b) earth resistivity.

(a) Self-potential measures the natural potential differences which generally exist between any two points on the ground. These potentials, partly constant and partly fluctuating, are associated with electric currents in the ground. Constant and unidirectional potentials are set up due to electrochemical actions in the surface rocks or in bodies embedded in them. Normally ranging from a fraction of a millivolt to a few tens of millivolts, self-potentials sometimes attain values of the order of a few hundred millivolts and may reveal the presence of relatively strong subsurface "battery cells." Such large potentials are observed, as a rule, only over sulphide and graphite ore bodies.

(b) Earth-resistivity is a measure of the distribution of earth's subsurface electric resistivity. This varies with depth and mineral composition.

Electric currents flowing through the ground to produce a potential difference between two points has been known for a long time. Some of these currents are artificial, caused by electric railways, power lines, etc., while others may be natural, e.g., those due to sulphide ores. Besides these local phenomena creating potential differences in limited regions there are currents caused by astronomic phenomena, such as solar electron streams, rotation of the earth, etc., which cover extremely large areas. These currents flow in vast sheets involving the entire surface of the earth and are called telluric currents. These telluric currents are of the order of 10 mV/km and are constantly fluctuating in direction and magnitude at any point.

Geomagnetism (7,8,13,32)

The regular geomagnetic field may be represented as the field of a dipole situated at the center of the earth with its magnetic moment pointing toward the earth's geographical south. Physically, the origin of the field seems to be a system of electric currents within the earth. At any point on the earth's surface, the magnetic field vector (F) is specified by its horizontal (H) and vertical (Z) components and the declination (D), west or east from the true north, of H. H is always reckoned positive, but Z is reckoned negative if it points upward (as in the southern hemisphere) and positive if it points downwards. The inclination (I) is given by $\tan^{-1} Z/H$. The points on the earth at which $I = \pm 90^\circ$ are called the magnetic north and south dip poles respectively. Aside from many such points due to local anomalies, there are two main north and south dip poles situated at 72°N, 102°W and 68°S, 146°E. These do not correspond to the intersections of the axis of the imaginary dipole at the earth's center with the surface which are at 79°N, 70°W and 79°S, 110°E. The latter are the geomagnetic poles or axis poles. For convenience, the two magnetic poles are called by the name of their nearest geographic pole, although the north geomagnetic pole is at the geographic south pole. The imaginary line on the earth's surface passing through the points at which $I = 0$ is called the magnetic equator. North of it Z is positive, south of it negative. The value of the vertical force Z varies from zero on the magnetic equator to about 0.6 gauss at the magnetic poles; the horizontal component, H varies from zero at the poles to about 0.3 gauss on the magnetic equator. Thus F, the magnetic field vector, varies from 0.3 to 0.6 gauss. In a few disturbed localities F drops below 0.3 gauss or rises above 0.6 gauss to 3.0 gauss or more at some points.

$$F^2 = H^2 + Z^2 \qquad H \cos D = X$$

$$H = F \cos I \qquad H \sin D = Y$$

$$Z = F \sin I \qquad \tan D = Y/X$$

$$Z/H = \tan I \qquad H^2 = Z^2 + Y^2$$

X and Y represent the northern and eastern components of H.

The earth's field is not constant at any point on its surface but undergoes variations of different periods. The most important of these are the diurnal variations and magnetic storms. The following table gives values of H, Z, and D for 1950 at some selected places on the earth's surface. (32)

Latitude	Longitude East	H	Z	D, East
+ 80.3°	52.8°	0.062 gauss	0.549 gauss	+ 25.4°
+ 69.7°	18.9°	0.112	0.506	- 1.1°
+ 51.2°	359.6°	0.186	0.433	- 9.3°
+ 37.8°	334.3°	0.024	0.391	- 16.7°
+ 18.6°	72.9°	0.384	0.177	- 0.7°
- 6.2°	106.8°	0.374	-0.237	+ 1.4°
- 20.1°	57.6°	0.223	-0.304	- 15.7°
- 30.3°	115.9°	0.248	-0.520	- 2.8°
- 54.5°	159.0°	0.134	-0.645	+ 23.9°

The total magnetic moment of the earth is 8.1×10^{25} cgs units, (7,8, 13) corresponding to an intensity of magnetization of 0.08 cgs unit per ml for the entire substance of the earth on the hypothesis of uniformly distributed magnetization. Although this magnetization is several orders of magnitude less than that of the best magnet steel, it is still many orders of magnitude greater than is observed in ordinary rocks. ($1\gamma = 10^{-5}$ cgs unit).

Measurements of the earth's magnetic field at the same place, but separated in time by several years, have revealed that the magnetic intensity is changing in magnitude and direction. Four major aspects of change have been noted: (1) changes in total magnetic moment of the earth; (2) changes in direction of magnetization; (3) irregular changes of apparently local origin; (4) changes in the external field.

The earth's magnetic moment has been decreasing at a rate of 1/1,500 per year over the last century. If this apparent change continues, the earth's magnetic moment will be reduced to half its value in 1,100 years. If this change is extrapolated backward in time, the present value of 8.6×10^{25} cgs might be compared to values of 3.4×10^{26} at the age of Socrates, 5.5×10^{27} cgs units at the dawn of history, and 8.0×10^{28} at the time of Cro-Magnon man. (The value Ho corresponds to the magnetic moment of the earth's field. In 1922, Ho = 0.316 gauss which corresponded to a magnetic moment of 8.19×10^{25}. The magnetic moment, $M = a^3Ho$ where a is 6370 km, or $M = \frac{4}{3} \pi a^3 J$ where J is the intensity of magnetization, and a is the earth's radius.) (8)

THE BIOTIC ENVIRONMENT

The Biotic Environment consists of that environment resulting from the interactions of living organisms with each other and with their physical environment. As a result of these interactions, a dynamic condition is created in which the biotic environment undergoes moment to moment changes. These dynamic changes involve every facet of the organism's chemistry and physiology since each response to an external condition creates a new environment which in turn reacts to a variety of surrounding or subjacent conditions or to other factors that may impinge upon it. This continuous state of flux exists at the molecular, subcellular, cellular, and organismic levels, with each level capable of reacting with its own as well as those above and below it. Hence, the biotic environment is, indeed, a complex, dynamic situation which cannot be expressed in static terms. However, an attempt will be made to list some of the variables that influence or may be influenced by the physical and biotic environments and which form part of the total biotic environment.

Organismic Variables (Internal Milieu and External Response)

Unicellular Organisms

ph
respiration-photosynthesis
feeding
excretion
reproduction
mutation
absorption
diffusion
permeability
chemical changes
electrical activity
sol-gel state
contraction-relaxation
behavior-physical
orientation
rhythms
movement
courting-mating
defense-offense
luminescence
symbiosis
parasitism
ciliary activity
tropisms
regeneration
adaptation

Multicellular Organisms

All of the foregoing listed for unicellular organisms plus the following:

Locomotion
Behavior - group interaction
Reflexes
Instincts
Homing - migration
Communication
Learning - adaptation
Sensory system
- vision
- auditory
- olfactory
- kinesthesic
- other

Sound production
Muscular system
Skeletal system
Digestive system
Excretory system
Reproductive system
Development - metamorphosis
Growth

Cardiovascular
Blood
Respiratory system
Digestive system
Nervous system - central
- peripheral
- autonomic

Resistance - susceptibility
Antigen - antibody interactions
Secretion
Chemical interactions
Physiological interactions
Hormonal changes
Mimicry
Psychological changes
Balance and posture
Molting
Integuementary system
Tissue fluids
Temperature - deep
- surface

The most fundamental of the characteristics of living organisms is the way in which, in the face of an environment which presents as many dangers as opportunities, they hold their own by making adjustments within themselves. This phenomenon applies equally to the struggle for existence of the individual and to the slow, racial adjustments known as evolution. The term "environment" is a collective name for all external things which affect any living being. In general, four principal factors constitute the environment:

(1) The ground or "substratum" upon which the organism stands

(2) The "medium," water or air, which bathes the organism

(3) The physical energies it receives from or can lose back to its surroundings

(4) Other organisms in its neighborhood

The action of the environment upon the organism is threefold: (1) it affects the organism mechanically, as by transporting it from place to place, by the impact of adjacent objects, or by the attacks of enemies; (2) it affects the working of the living machine by the compulsory introduction or extraction of materials (water, salts, etc.) or of energy; (3) it directly stimulates the organism to activity, which may be an inevitable response, such as the movement of certain organisms towards light, or depend upon conditions existing at the moment in the organism, or it may inhibit such activity. In addition to such action, the environment may affect the organism adversely by failure to provide food, respiratory gases, or some other necessity which the organism is dependent upon obtaining from its surroundings. However, when failures occur, from time to time, the organisms usually have a means of enduring them (reserve stores, resting stages, etc.); otherwise the species would fail to survive.

Time

The parameter of time is present in both the physical and biotic environment. In both environments time is a physical variable expressed in terms of earth's relationship to the sun as a result of its rotation and revolution. However, in the biotic environment such a measure of time has different meanings for different organisms. The concept of a day as a unit of time has no meaning for an organism whose total life span is no more than several hours. Thus, response to environmental changes may require exposure of one organism for many generations, while another may respond in its own lifetime, the chronological, physical time factor being the same for both. Therefore durations of exposure to environmental variables should be expressed in terms of chronological, physical time as well as in relation to the experimental organism's life span or to some other biological event that is a meaningful yardstick for the particular organism.

Temperature

Each species of organism is capable of carrying on its metabolic activity only within a certain limited range of temperatures. At some point within this range, usually above the middle, but sometimes below, the vital processes function at their optimum. For most animals the lower limit is slightly above freezing, while the upper limit is usually below 45°C. Fish eggs develop best a few degrees above freezing, birds' eggs at about 40°C. Some animals have the ability to adjust themselves to temperatures beyond their usual range. For example, some protozoans which die when the temperature is rapidly elevated to 23°C. will survive 70°C. if the increase is very gradual. As indicated in the section on the Physical Environment, the temperature on earth varies with latitude, elevation, season and diurnal rhythm. Animals must be so located that their permissible temperature range is not exceeded by the environment. Hence temperature acts as a selective mechanism for limiting organisms to specific geographical locations. However, some animals can survive extremes in temperature ranges by specialized habits and temperature regulating mechanisms.

Temperature also influences the rate of biological reactions, germination and development, behavior and mutation. For example, many seeds must spend a period of dormancy at reduced temperatures, otherwise they will not germinate. Grasshopper eggs develop more rapidly at their optimum temperature if that temperature has been interrupted by a cold period. Acceleration is greater if the interruption by low temperature comes early than if it comes late in development. (37) Similarly, development of amphibian eggs can be retarded by lowering the temperature. Hibernation, an example of depressed metabolic activity, is temperature dependent, among other factors. Reaction to the temperature of the water enables the Alaskan salmon to reach its breeding waters. (31) Development of wings in some aphids seems to be temperature controlled. No general rule can be given for this control of wing production since different strains, even within the same species, respond differently. One of the leaf-boring beetles, as another example, moves toward the light at high temperature but withdraws from the light at low temperature. Mutations have been produced in Drosophila by heat. The amount of separation and recombination of characters due to breakage and reconstitution of chromosomes by exchange of pieces is increased by high temperature.

Temperature not only functions alone but also is related to other environmental factors. Skholl (41) studied the effect of temperature and oxygen on the duration of irritability and rate of protein synthesis of isolated rat muscle fibers. Under the action of oxygen and at a temperature range corresponding to the body temperature of mammals, there was temperature adaptation in isolated muscle which was manifested by an increase in the time irritability was maintained. In addition, the cells also showed a sharp increase in the rate of protein synthesis.

Temperature effect on the ability of the newt, Triton cristatus, to regenerate excised ovaries was reported by Artem'eva (2). He divided the newts into three groups: control (16-25°C), high temperature (30-33°C), and low temperature (10-13°C). Each group experienced three series of experiments as follows: first series, half of the left ovary removed; second series, entire left ovary removed; third series, entire left ovary and half of the right ovary removed. Changes in temperature, represented by the three experimental groups, affected the course of the process of hypertrophy and regeneration. At the increased temperature, regeneration of the ovaries was slower than in the controls. The reduced temperature stimulated compensatory hypertrophy which led to regeneration of the ovaries.

Temperature has a bearing on the photosynthetic process, which it may reduce considerably, as is evidenced in aquatic plants. (28) In woody plants, the ratio of starch to sugar increases from the coldest to the warmest months. (16) The white fish will not feed at temperatures above 25°C; as a result, entire populations may remain composed of small-sized individuals. (14)

Most frequently temperature is associated with relative humidity. This combination of conditions affects a wide variety of biological processes. In a study of the beetle, _Tribolium modens_, Howe (19) demonstrated that temperature and relative humidity affect the rate of development and the mortality of this animal. The shortest mean developmental period for _T. modens_ is 25 days at 35°C and 70% relative humidity (the range being 20-35°C). Under these conditions, the sex ratio is predominantly in favor of females. At 37.5°C and 80% relative humidity there was no effect on the rate of development of eggs or pupae. Larvae developed faster at 70% and 90% relative humidity than at lower percentages. At 70%, eggs, pupae and larvae grew quickest at 35°C, but at 50% relative humidity, optimum growth temperature was 32.5°C.

Survival and reproduction rate of the spotted alphalfa aphid and pea aphid are influenced by temperature and humidity. As a rule, humidity had less influence than temperature on aphid biology. (21) However, the effect of temperature is conditioned by humidity. At 85°C survival of adults and the number of live nymphs produced per adult differed significantly with humidity, but humidity was insignificant at 55°F.

Illumination

The most important role of illumination is in the photosynthetic process of green plants. Plants dependent upon photosynthesis for their nutrition can maintain themselves only where sufficient light is present. Animals dependent upon these plants for their nutrition are therefore limited to the range of the plants. In deep lakes, for example, green plants are limited to the surface water, if floating, and to a strip along the shore, if rooted. (12)

A very important effect of illumination is the daily duration of light on the diurnal cycle. Many plants and animals depend upon this variation for the proper stimulus for their reproductive process.

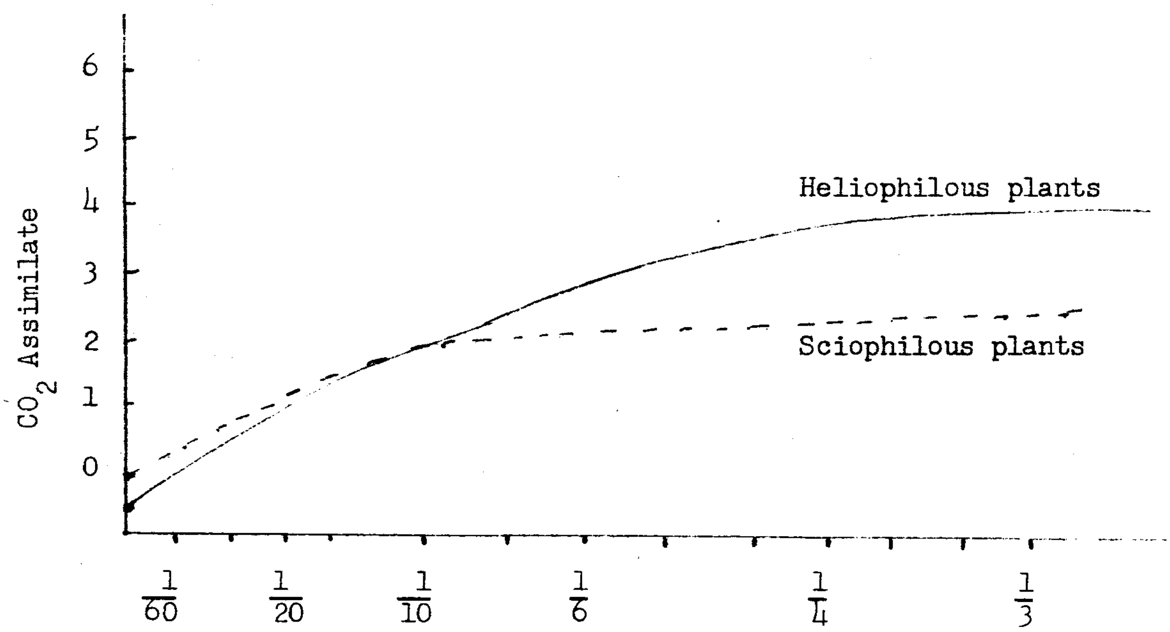
The intensity of illumination is responsible for color changes in animals, behavioral patterns (phototropisms), feeding patterns, life cycle relations (parasitism), growth and development of plants, and morphological modifications.

The biology of the gray field mouse, Microtus arvalis, is particularly responsive to changes in illumination. Bashenina (3) devised two experiments, one over a $3\frac{1}{2}$ and the other over a 6-month period in which he studied the reproduction, growth, development, and thermal regulation in relation to varying lengths of daylight. The experimental illumination consisted of 10-12, 9 and 6 hours of daylight and complete darkness. With prolonged illumination, the number of young increased, deaths were not noted and growth improved. Under least daylight, there was poor growth, loss of weight, and a weakening of chemical thermo-regulation. Full darkness resulted in maximum weight loss, rapid exhaustion of reproductive capability in the female, cessation of lactation, and death of the young.

Light, temperature and high frequency radio waves were studied by Vernick (48) as affecting embryonic development of the fish, _Tilapia macrocephala_. Microcephaly, macrocephaly, vertebral column deformations, and length of time required for embryonic development were associated with changes in temperature. Little effect was noted due to light, however, _Tilapia_ embryos were sensitive to the red end of the spectrum. Exposure to high frequency waves results in 5% survival. This 5% which survived came from a group which was initially exposed to 3730 Kc for 30 minutes in the hatching stage. No developmental abnormalities were apparent.

A vast literature exists on the effects of illumination and temperature on agricultural and live stock production. Reports have related these parameters to yields of wool, milk, eggs, etc. Schutze (39) as an example, reported a study of the influence of light on the economic and physiological characteristics of chickens. White leghorn pullets were exposed to six different photoperiods. Those pullets exposed to 9 hours light per day at hatching with an increase to 16 hours daylight by 20 weeks of age laid their first eggs at 18 weeks, which was 1-5 weeks earlier than pullets exposed to other light treatments. Exposure to 16 hours of light at hatching then reducing the light to 9 hours at the end of 20 weeks resulted in a higher rate of egg production than other light regimes. Constant 8 hour light produced no change to increased light. However, exposure to 22 hours light at hatching then reduced to 16 hours by 20 weeks produced heavier eggs than other light exposure treatments.

Illumination is important for the photosynthetic process, yet not all plants accelerate photosynthesis with increased light. (10) Heliophilous species of plants, such as raspberry and bracken, do best in full sunlight. Sciophilous plants, on the other hand, increase photosynthetic activity up to about 10% of full light, and thereafter do not substantially improve. The increase in intensity of assimilation is greater when nearest the minimum point. (26) With sciophilous species, there is an early check in proportionate utilization (See following graph). (26)



Reproduction of plants is influenced markedly by illumination—photoperiodism. Some plants require long days, others short days before they will flower and reproduce. A good example is the chrysanthemum which will not bloom unless there is a short day period. Hence the plant does not flower until late autumn when the amount of daily illumination is reduced. (10)

Depending upon light exposure, the physical form of mussels will vary. The three dimensions of growth will show a different ratio, thus length will increase more rapidly than depth and width. As a result mussels of very different shapes are produced which show marked morphological divergence from those grown in full light. (20) Changes in morphology due to illumination differences are, perhaps, more pronounced in some of the plants than in animals. The lobation of leaves is very often a sensitive indication of light in dandelions, oak and bracken. Germination is also affected or perhaps influenced by amount of light falling on the seeds. Some plant seeds germinate in the shade and others in the light. Tropical umbrella-trees germinate in full sunlight. But as the tree grows and develops a full crown, it casts shade and prevents germination of its own seed that has fallen close by. (10)

Another response to light seen in plants and animals is phototropism. Some plants and animals are positively and others negatively phototropic, that is, they either move toward the light or away from it. Some trees show a strong negative phototropism, their leaves orient themselves vertically to the light source thereby exposing minimum surface area to the illumination. (12,34)

Humidity - Moisture

All organisms contain a large percentage of water without which normal living processes could not function. Although no animal can endure total dessication, there are organisms which can survive extremely dry conditions. Protozoa may become encysted and survive in a dried state. Bacteria may survive dessication in the spore form. (29) Eggs of many crustacea and rotifers, covered with heavy shells, may be dried without deleterious effect.

Many soil organisms will burrow deeper as the moisture is depleted near the surface. Earthworms eventually roll up into a ball to conserve moisture if the soil becomes too dry.

Excess moisture can be equally detrimental. Soil organisms may be drowned by having moisture drive the air out of the soil. Excess moisture may lead to putrefaction and noxious chemical products.

The problem of water management is vital to all living things. The dependence upon water determines the geographical distribution of many organisms. However, any consideration of humidity carries with it a concomitant consideration of temperature because of the related physical events of evaporation and precipitation. In cases of high temperatures, increased evaporation reduces the net available moisture. Conversely dry protoplasm can endure high temperatures, even above boiling, without coagulation and low temperatures without freezing (viz. the process of lyophilization for preservation of living tissues and of microorganisms).

Water availability is extremely important in the life cycles of plants and animals. Such critical events as germination, reproduction, and hatching are dependent upon adequate moisture. The defense against drought is visible in xerophilous plants, cacti and other succulents, which accumulate water and have special mechanisms for resistance to evaporation. To achieve this end, many morphological variations are exhibited, such as reduction in leaf surface, substitution of leaves by spines, epidermal production, secretions, etc. (38) The shapes, thickness, and cellular development of leaves are very sensitive indications of differential water availability in contrasting habitats, as in broad-leaved and needle-leaf trees. (17,45) Other physiological devices are used by plants to conserve moisture. Some mosses contract the chlorophyll grains (30) and ferns curl up their leaves. (1)

Many mammals are susceptible to humidity and moisture conditions. Dry conditions in the environment can reduce the population of small mammals by restricting reproductive ability. The mouse-like marsupial Sminthopsis crassicaudata, which has typically ten nipples, produces ten young at birth under conditions of normal moisture, but no more than 4 or 5 during dry seasons. (6) Many animals which live in dry climates have become adapted to subsist on little water. These creatures depend solely upon the minute quantities of water found in seeds and dead plants which have become completely air-dried. Good examples of such animals are the Egyptian Jerboa (6) and Perognathus of the American southwest. (25)

Pressure

Changes in barometric and ismotic pressure elicit responses in many biological organisms. Some of the most amazing changes in osmotic pressure regulation are found in some fish. The migration of the Atlantic Salmon, which lives in salt water and spawns in fresh water, and the eel, which lives in fresh water and spawns in the Sargasso Sea, imply a ready adaptation of internal fluids to changes in osmotic pressure. (31)

The Controlled Energy Environment

The preceding section briefly indicates some of the variations occurring in the biotic environment as a result of specific changes in the physical environment. The section to follow will deal more specifically with biotic variations encountered as a result of specific modifications in the physical environment. These variations will be considered from the aspect of how they will affect unicellular and multicellular organisms. Because of their simple organization, unicellular organisms will not exhibit the complexitv of possible effects that may be encountered in the multicellular organisms. But any of these responses might be exhibited by any one of the component parts (cells) that make up the multicellular organism.

In considering the biotic environment as a function of the physical environment, certain important points must be kept in mind.

The basic physical environment must maintain those parameters vital to the life of the organism within optimum limits, otherwise any changes in the energy imputs would lack meaning. Parameters of temperature, atmosphere, and nutrition must be maintained as constants except in those instances where any one of them may be the variable. Limits of any input variable must not exceed natural extremes. Exceeding these natural limits changes the aim of this study. Since any magnitude variable may be used to investigate physiological responses, the elicited response is not indicative of the changes obtained in the more limited natural energy change.

Because of the magnitude of modifications and changes that can occur in the biotic environment as a response to the physical environment, the parameters considered have been limited to the major, fundamental ones shared in common by all biological organisms. Any attempt to have done otherwise would have been a naive effort to reiterate the total science of experimental and environmental biology.

The distribution and survival (the ultimate biological response) of many unicellular and microorganisms is dependent upon their external environment. The same statement, but with some reservations, applies to multicellular and highly complex organisms, including man, as well. Kriss (24) collected over 4000 strains of heterotrophic microorganisms from all the oceans, extending from north to south pole, at depths and from the surface. The capacity to metabolize protein and carbohydrate and to use bound oxygen and inorganic nitrogen compounds was investigated. Fewer biochemically active organisms were found in the equatorial-tropical zone than in the high latitude areas. Many microorganisms with many-sided enzymatic activities were present in populations located in the near-polar areas. This resulted in more profound transformations of organic matter in the waters of these areas as compared with tropical area waters. Consequently an increased concentration of biogenic substances was found in the near-polar waters. A unique exchange occurs between areas of the low latitudes and those of the high latitudes. Currents driving equatorial-tropical waters to the north and south carry organic matter. This material is more completely decomposed by microbial species which inhabit the high latitudes. Liberated biogenic substances are carried by currents into the depths of other geographic areas, thus increasing the reserve of substances taking part in the primary production of organic matter in these areas.

The salinity of the sea also seems to play a role in the distribution and survival of many of the sea's inhabitants. In many cases, salinity is related to other parameters such as temperature and light, and effects produced may or may not be synergistic. The chubpolyp (Cordylopora caspia) is normally found between 20° - 60° north latitude in brackish water not exceeding 10% salinity. However, it might also be found in fresh water where a combination of five physical parameters exist, viz., rapid flow, acid pH, proper amount of illumination, temperature below 20°C., and a suitable concentration of nutrients. Yet in laboratory cultures, this same organism will thrive between 18° - 20°C in 35% salinity. (23)

Many of the organisms that cause fouling of ships, pilings, etc. are responsive to changes in salinity. Turpaeva and Simkina (47) studied the reaction of the barnacle, Balanus improvisus, to salinity below normal levels (18%). Reduction of salinity to 12% still resulted in normal growth. However, under 8% salinity partial growth inhibition occurred, and at 3% there was permanent inhibition of growth. In fresh water, all the animals died.

The bivalve mollusc, Teredo navalis, varied in its survival rate depending upon the salinity of the water. (42) Normal environmental salinity is 18%. At 10% or 28% salinity, after 2 months, 60% of the animals survived. At 30-35% salinity, there was about 30% survival rate after one month, and at 40% salinity there was only a 2% survival after 3 months. Thus, differences in salinity in different parts of the world's oceans serves as a factor limiting the distribution of many forms of life. Although there are marginal areas which are not conducive to optimum survival, many animals do survive because of their ability to adapt or because the right combination of other parameters is present.

The process of acclimatization or adaptation to extreme environments is not one of abrupt change but rather of gradual adjustment accompanied by disturbances or modifications in the "biotic environment" or internal milieu. A good illustration may be drawn from reports of human responses to life in extreme northern climates. Chekin (9) surveyed the physiological changes in subjects who underwent a process of acclimatization to subarctic atmospheric conditions. The types of individual reactions were disclosed. One group of persons underwent a gradual reorganization of the adaptive mechanisms after a short period of disturbances in function of the cerebral cortex, subcortical centers, autonomic nervous system, hypothalamus, and endocrine system. The second group of individuals developed disturbances of the nervous and endocrine systems which caused fatigue, drowsiness, general weakness, myalgia, arthralgia, and cardialgia. The majority of individuals developed various degrees of thyroid gland hypertrophy and disturbances in adrenal function. Even healthy, adequately fed individuals required a supplementary intake of vitamin C. An extended drop in atmospheric pressure in connection with periodic seasonal changes may result also in increased blood pressure which may persist for months. Examination of permanent residents of the far north revealed that they have metabolic rates higher than that of individuals from temperate zones. Newcomers to the arctic region underwent a drop in metabolic rate which persisted for years. (22) In permanent arctic residents, the mechanism of acclimatization became automatic, but newly arrived persons became either hypothermic or hyperthermic. Subsequently these individuals developed trophic disturbances of the upper respiratory tract, the muscular system, the nervous system, and the internal organs. The differences in somatic and peripheral temperatures caused an overload on nonconditional reflex functions of the nervous system. The excessive respiratory volume decreased the period of pulmonary rest changing the disposition and size of the thoracic cavity. This resulted in a stasis of pulmonary circulation, hyperemia of the lungs and liver, a decrease in blood flow rate, and capillary fragility. Prolonged days or nights produced a stress on the nervous system.

Environmental Interactions

In the following section an attempt will be made to take the data previously presented, resynthesize it, and devise representative schematic diagrams which will illustrate the extent of environmental interaction. This refers not only to the interaction between subject and environment, but also to the biotic environmental interaction which may be considered as an intrasubject response to the various energies impinging upon the biological organism. In devising these schematic representations, background material will be drawn not only from this study but from the vast storehouse of past, general biologic and related experience. In addition, a final critique will be presented on the problems involved in a controlled-stimulus environment.

A controlled environment is important in biological research for many reasons. In the past, observations made in the field, under natural environmental conditions could not be duplicated under laboratory conditions because the total environment was not duplicated. An organism in nature is subjected to many variables which are not always constant. The response of the organism is not always the sum of the individual responses to the separate parameters, nor is it a predictable vector response.

Thus if P equals any environmental parameter, then

$$P_1 \longrightarrow \text{organism} \longrightarrow E_1$$

acting on the organism a specific effect, E, is produced. Similarly,

$$P_2 \longrightarrow \text{organism} \longrightarrow E_2$$

$$P_3 \longrightarrow \text{organism} \longrightarrow E_3 \cdots\cdot$$

But,

$$\begin{tikzcd} P_1 + P_2 + P_3 \arrow[r] & \text{organism} \arrow[r, "/" marking] \arrow[dr] & E_1 + E_2 + E_3 \\ & & E_x \end{tikzcd}$$

The effect of a sum of environmental parameters is not predictable for many reasons. The effect may be the result of synergistic action of the parameters. It may be the result of antagonistic action. The combination of factors may make the organism refractory so that it does not respond at all; it may precondition the organism to give an exaggerated response; there may be potentiation of effect. However, in a minimum environment, the addition of environmental conditions should elicit interesting responses. Since a stimulus-free environment is a nonexistent situation, the minimal stimulus environment in itself can cause a response. Perhaps, then, rather than start with the few and increase to the many, it might be advantageous, from a biological viewpoint, to commence with the normal complex, multiple factor environment. With this starting point, individual parameters can be removed by the appropriate shielding or alteration of conditions. Let us critically examine the environment and determine what is biologically minimal.

Temperature, atmosphere, illumination, and gravity must be present. Of these four, only gravity can be removed, under the appropriate circumstances.

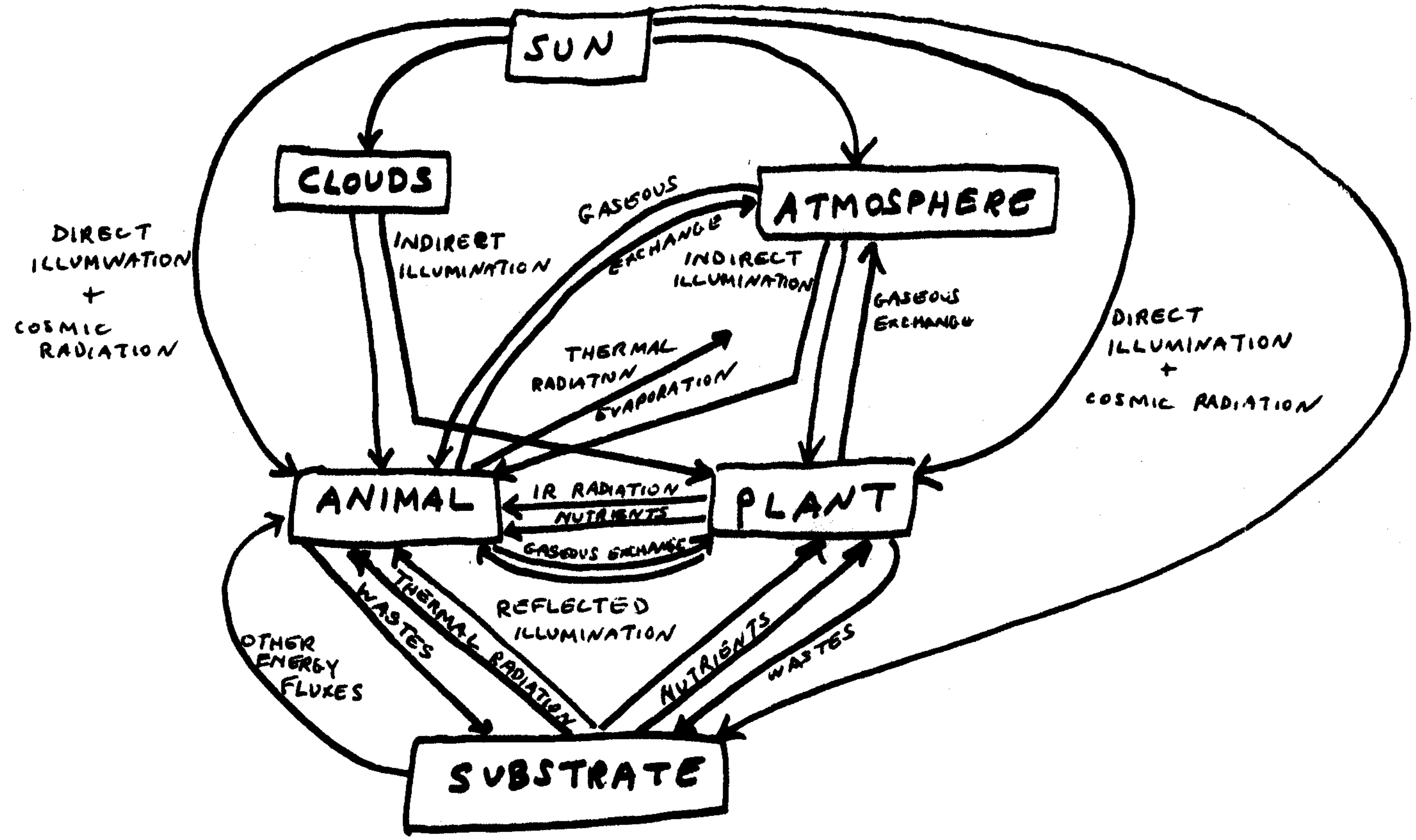
Temperature and atmosphere are perhaps the two most vital conditions in the environment absolutely essential for biological survival. All living things, regardless of whether they are poikilotherms or homotherms have critical temperature ranges beyond which death ensues. Below a certain point, biological processes stop. Above a certain temperature, the material of living things, protoplasm with its high protein content, coagulates and death results. Life is more tolerant of the cold since under extreme conditions of cold, with the proper organism, the living processes may be suspended and maintained in a dormant state capable of returning to full functional activity. Many viruses and bacteria have been preserved by freezing with full viability returning upon thawing. However, with the majority of members of the plant and animal kingdoms, the effects of very low temperatures are relatively unknown because death intervenes early. In experiments with freezing, other factors enter the picture such as rate of temperature drop, state of hydration of specimens, and cell size of specimens. Again, in this situation there is no simple alteration of just one, single parameter. For biological material, a temperature-free environment cannot exist. The temperature must be restricted to those rather narrow ranges that are compatible with life.

Atmosphere is another environmental factor which is variable but without which life cannot exist. Some form of gaseous interchange exists between organism and environment. Organisms have been known to exist in vacuo, but at the same time other parameters have been modified. The process of lyophilization uses a hard vacuum to preserve cells, viruses and bacteria, but this is accompanied by freezing and drying. For normal biological function, some gas is required, be it oxygen, nitrogen, carbon dioxide, methane, or ammonia depending upon the particular life form.

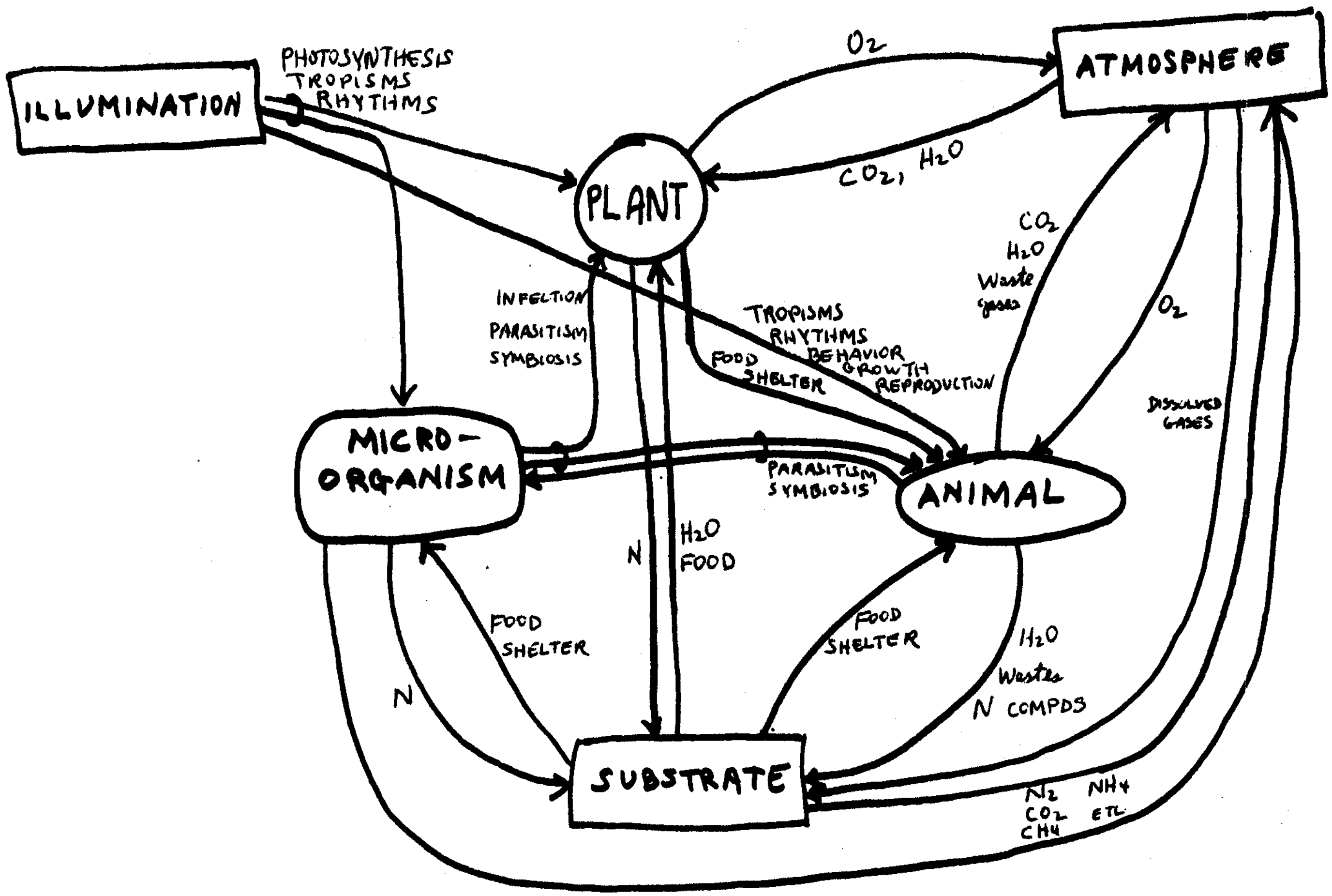
Atmosphere and pressure are closely linked together. The mere presence of atmosphere creates a pressure exerted by the atmospheric constituents. As with temperature, the pressure range is limited, beyond which limits deleterious effects result with ultimate death. With the advent of advanced technologies that enable man to enter the heights of the atmosphere and the depths of the seas, a vast experimental literature has appeared on the effects of compression and decompression. Experimenters have pointed out the narrow range of pressures that life can tolerate without protective means.

Illumination is another environmental parameter that is always present. Darkness, the absence of illumination, is just as important and powerful an environmental variable capable of stimulating things as is illumination. Since biotic limits of the physical environment cannot conceive a temperature-less, atmosphere-less, and pressure-less situation, by the same token, it cannot conceive an illumination-darkness-less environment.

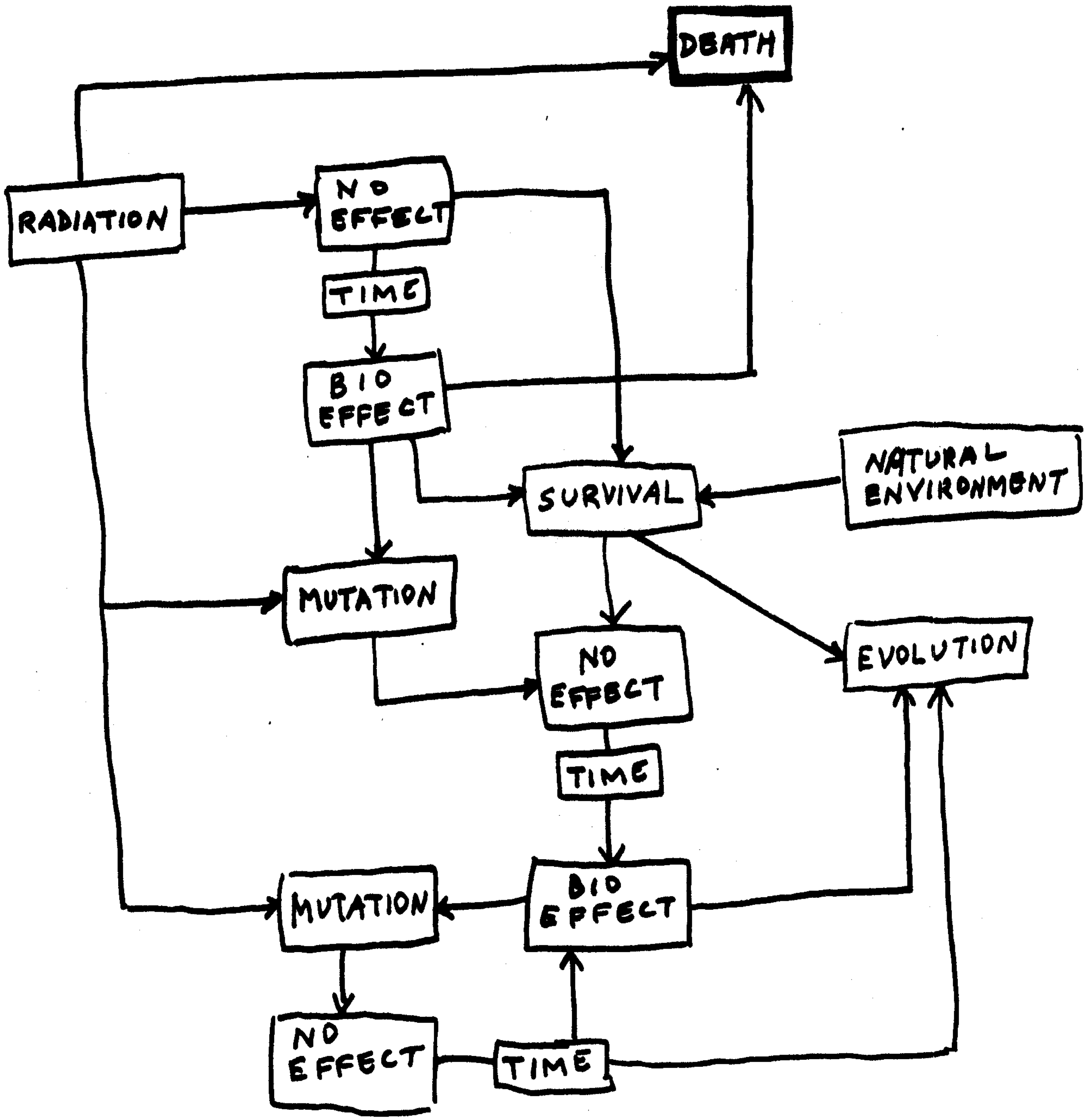
Other factors in the environment can be removed or modified more easily. Shielding can be provided against a variety of physical energies and forces so that their presence is eliminated. It is the presence or absence of these many energies and forces that may play important roles in the total life process. "Trace" amounts of these factors may be required for normal biological functioning. The interrelations of these energies and forces with the resultant effect upon biological economies make the prospect of being able to control them accurately so intriguing.



ENERGY EXCHANGE IN THE NATURAL ENVIRONMENT

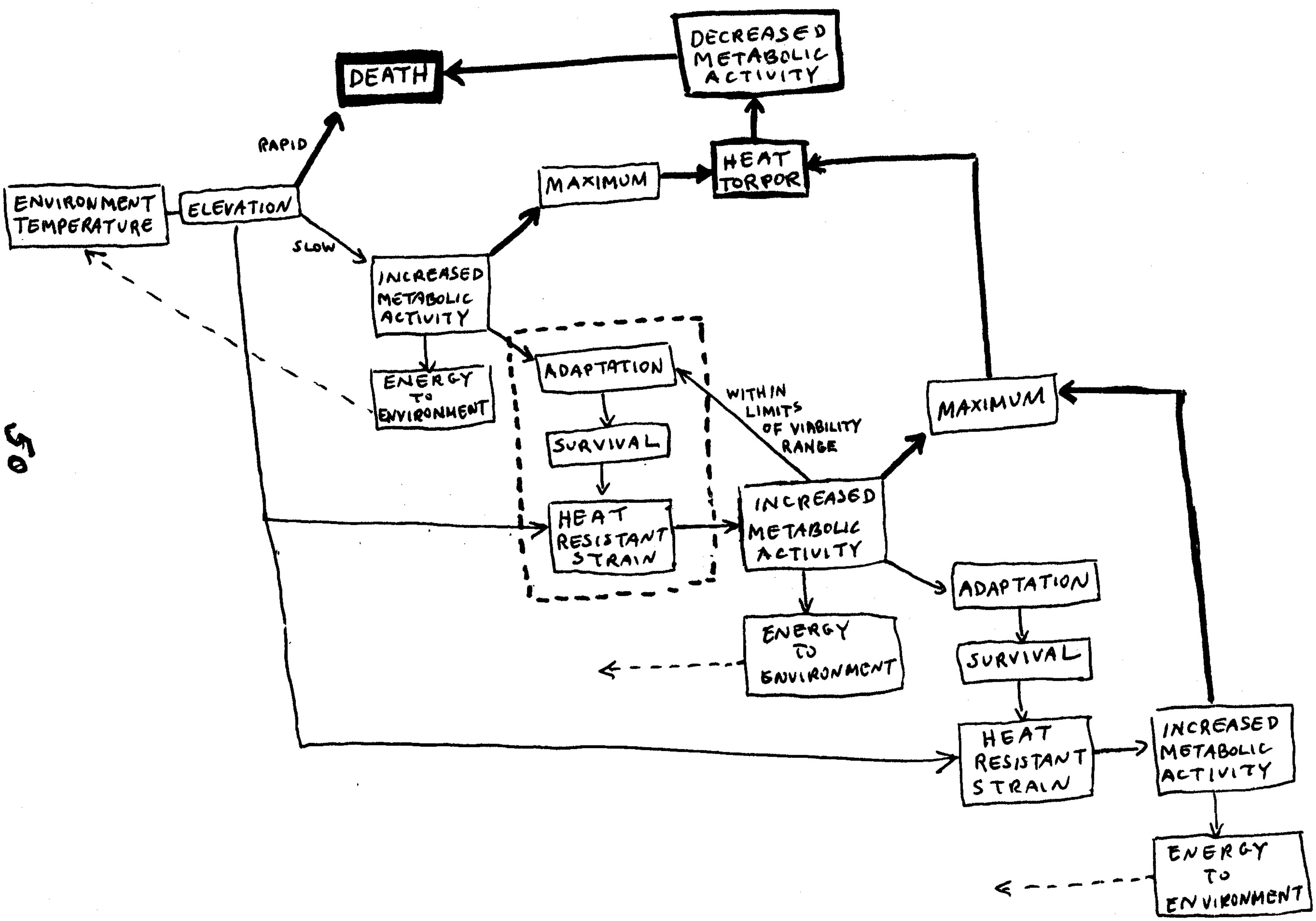


BIOLOGICAL INTERACTION IN A LIMITED ENVIRONMENT

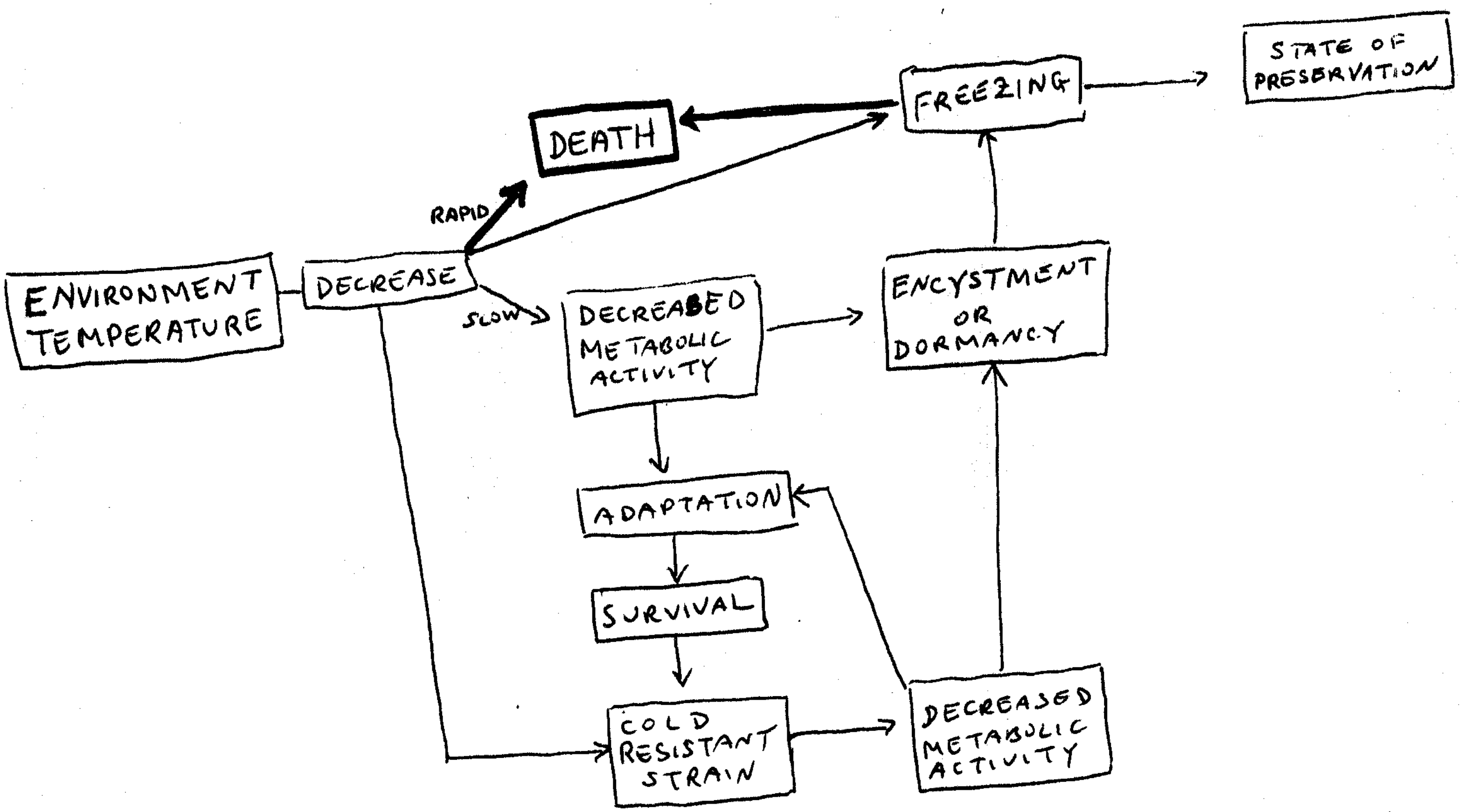


Radiation Response by Living Material in General

PROTISTA



TEMPERATURE RESPONSE OF SINGLE CELLED ORGANISMS



Temperature Response of Single-cell Organisms

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